New York Climate Action Council Scoping Plan

Technical notes and comments prepared by Raymond J. Albrecht PE

Summary Biography for Raymond J. Albrecht PE

Consulting environmental engineer with over 40 years of experience in the subject area of renewable heating technologies. Technical specialties have included electric and thermally-driven heat pumps, solid and liquid renewable fuels in thermal applications, and power generation. Have performed work for manufacturing companies, trade organizations and environmental agencies relating to equipment design, fuel utilization, regulatory permitting, emissions testing, and life-cycle analysis. Member of the ISO New England Planning Advisory Committee and active with the ISO New England Load Forecasting Committee. Spent 30 years as technical staff person for heating technology and fuels R&D at the New York State Energy Research and Development Authority (NYSERDA). NYSERDA work also included field testing of first ground-source heat pump installation in northeastern United States back in early 1980s. Principal of Raymond J. Albrecht LLC for the past 14 years.

Graduate of Cornell University with a Bachelor of Science degree in engineering and a Master of Science degree in Theoretical and Applied Mechanics. Life Member of the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) and past chairman of ASHRAE Technical Committee 6.10 for Fuels and Combustion. Received the ASHRAE Distinguished Service Award in 2015. Licensed professional engineer (No. 056935) in New York. Served as a 1st Lt (Infantry) in the United States Army during 1970-80 (active plus reserve) and am a graduate of the US Army Infantry Officer School at Fort Benning, Georgia. Fulfilled my active reserve obligation in northeastern Kenya, near the Somali border.

SUMMARY OF COMMENTS

1) There is increasing urgency for reducing the carbon footprint of space heating in residential and commercial buildings. While NYSERDA and the NYS Public Service Commission are to be commended for their accomplishments in the development of wind and solar generation resources across New York, the planned pace of renewable energy development in the state is too slow to meet the additional grid loads that would be incurred by full implementation of heat pumps for space heating. Required grid capacities would double or triple, due to an additional 40,000 to 50,000 MW peak load for heat pumps, even with the installation of massive quantities of battery storage, and ambitious efforts to reduce building envelope losses. New York should follow a dual pathway, to include increased use of renewable fuels such as biodiesel, in accomplishing its carbon savings goals in residential and commercial buildings.

2) Energy policymakers need to incorporate life-cycle analysis of natural gas for power generation in their analysis of energy resource options for buildings. The Argonne National Laboratory GREET model and UN Intergovernmental Panel on Climate Change (IPCC) have both recognized the need to apply life-cycle analysis to **ALL** energy resources, including electricity. Accounting for both CO_2 and methane emissions during production and high-pressure transmission of natural gas used for power generation, the resulting carbon intensity increases approximately 30% above onsite-based values, with a significant downward impact on the level of carbon savings achieved by electrification technologies.

3) Energy policymakers need to use marginal emission rates, rather than average grid mix figures, when evaluating the impact of electrification policies on grid performance. Marginal emission rates more accurately account for cause-and-effect changes, including the increased use of fossil generation when intentional grid load increases, due to electrification, outpace the growth of renewable power generation capacity. The use of average grid mix figures will most often seriously underestimate the environmental cost of increased grid loads, and can also lead to double counting of the benefits of renewable power generation.

4) Carbon savings achieved by heat pumps will be limited to those which are achievable with natural gas-fired generation, until existing grid loads are fully met by renewable power generation, and further renewable capacity can then be dedicated to heat pump operation. There will thus be a significant time delay in the achievement of fully renewable electrification of thermal applications, which in turn impedes the accomplishment of our environmental goals, especially within the shorter timeframes that are becoming necessary to avoid catastrophic climate change.

5) When marginal emission rates and life-cycle analysis are used properly in the analysis of renewable thermal energy options, the findings include the conclusions that B50 biodiesel blends will generally achieve the same carbon savings as next generation, cold-climate heat pumps which achieve 25% higher COP values than existing heat pump technology. Further, B100 biodiesel fuel will achieve lower carbon intensity than heat pumps until at least 30,000 to 40,000 MW nameplate capacity of wind and solar has become operational in New York, above and beyond what would be necessary to serve existing grid loads. Biodiesel offers a highly effective, parallel pathway for achieving deep carbon savings and a sustainable energy future.

6) The analysis described in this document has illustrated data showing a wide variation in carbon intensity for electricity throughout the heating season. There is general recognition that Increased carbon intensity values occur during cold weather, due to higher grid system loads with operation of lower efficiency generation units. But higher carbon intensities also occur during morning and evening peak periods, due to efficiency penalties of turbine startup or ramping of power output to meet rapid swings in grid load. Variations of grid carbon intensity by a factor of two or three can frequently occur at the same outdoor temperature, due to short duration, peak grid loads. This then leads to the need for web-enabled heat pump control systems that favor the synchronization of operation to periods of low, grid carbon intensity. Energy policymakers need to recognize that we need to avoid heat pump operation during periods of high grid carbon intensity, when little or no carbon savings are achieved compared to traditional fossil fuel, and yet, cost increases occur for grid operation.

7) Recent field testing studies in New England have revealed a problem of heat pump underutilization by homeowners during the winter. Many homeowners are apparently purchasing heat pumps for primarily air-conditioning purposes, based on state and utility incentives which make the net cost of a heat pump cheaper than air conditioning-only models. NYSERDA needs to establish a comprehensive monitoring and evaluation program for its statewide heat pump program to rigorously evaluate the economic and environmental benefits of incentive programs.

8) NYSERDA and the NYS Public Service Commission should develop an integrated, year-by-year master plan for implementation of heat pumps and renewable power generation in New York. The plan should include hourly analyses, for each successive year, of expected heat pump-based grid loads and the renewable power generation that becomes available, on a dedicated basis, to drive the heat pumps. The goal of the plan should be to forecast, with high temporal resolution, whether the state will make progress toward its environmental goals, or if fossil fuel-fired generation will instead remain the primary power resource for thermally-driven grid loads.

REFERENCES USED IN PREPARATION OF TECHNICAL NOTES AND COMMENTS

As the first step in preparation of these technical notes and comments, I compiled and reviewed several key testing reports that have been published over the past six years relating to actual field performance of cold-climate heat pumps. The reports are listed below and represent the most frequently cited literature that has been published on field performance of cold-climate heat pumps.

1) Commonwealth Edison Company (2020). Cold Climate Ductless Heat Pump Pilot Executive Summary. Chicago, IL. https://www.comedemergingtech.com/images/documents/ComEd-Emerging-Technologies-Cold-Climate-Ductless-Heat-Pump.pdf

2) ISO New England (2020), Final 2020 Heating Electrification Forecast. Holyoke, MA. https://www.iso-ne.com/static-assets/documents/2020/04/final_2020_heat_elec_forecast.pdf

3) The Levy Partnership/NYSERDA (2019). Downstate (NY) Air Source Heat Pump Demonstration. Albany, NY. https://static1.squarespace.com/static/5a5518914c0dbf4226cd5a8e/t/5d963d39f515f87c7bafe3ff/1570127329734/TLP+ASHP+Demo+Presentation+9.26.19.pdf

4) slipstream/Michigan Electric Cooperative Association (2019). Dual Fuel Air-Source Heat Pump Monitoring Report. Grand Rapids, MI. https://slipstreaminc.org/sites/default/files/documents/research/dual-fuel-air-source-heat-pump-pilot.pdf

5) Center for Energy and Environment (2018). Case Study 1 – Field Test of Cold Climate Air Source Heat Pumps. St. Paul, MN. https://www.mncee.org/MNCEE/media/PDFs/ccashp-Study-1-Duplex.pdf

6) Center for Energy and Environment (2018). Case Study 2 – Field Test of Cold Climate Air Source Heat Pumps. Minneapolis, MN. https://www.mncee.org/MNCEE/media/PDFs/ccashp-Study-2-MPLS.pdf

7) Center for Energy and Environment/Minnesota Department of Commerce, Division of Energy Resources (2017). Cold Climate Air Source Heat Pump. Minneapolis, MN. https://www.mncee.org/MNCEE/media/PDFs/86417-Cold-Climate-Air-Source-Heat-Pump-(CARD-Final-Report-2018).pdf

8) The Cadmus Group/Vermont Public Service Department (2017). Evaluation of Cold Climate Heat Pumps in Vermont. Montpelier, VT. https://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/Reports/Evaluation%20of%20Cold%20Climate%20Heat%20Pumps%20in%20Vermont.pdf

9) The Cadmus Group/Massachusetts and Rhode Island Electric and Gas Program Administrators (2016). Ductless Mini-Split Heat Pump Impact Evaluation. MA and RI. http://www.ripuc.ri.gov/eventsactions/docket/4755-TRM-DMSHP%20Evaluation%20Report%2012-30-2016.pdf

10) Center for Energy and Environment/American Council for an Energy-Efficient Economy/Minnesota Department of Commerce, Division of Energy Resources (2016). *Field Assessment of Cold Climate Air Source Heat Pumps*. 2016 ACEEE Summer Study on Energy Efficiency in Buildings. https://www.aceee.org/files/proceedings/2016/data/papers/1_700.pdf

11) Steven Winter Associates, Inc./National Renewable Energy Laboratory (2015). Field Performance of inverter-Driven Heat Pumps in Cold Climates. VT and MA. https://www.nrel.gov/docs/fy15osti/63913.pdf

12) The Levy Partnership and CDH Energy Corp./NYSERDA (2014). Measured Performance of Four Passive Houses on Three Sites in New York State. Albany, NY. https://static1.squarespace.com/static/5a5518914c0dbf4226cd5a8e/t/5ab273db562fa758761512bd/1521644514205/Measured-Performance-of-three-Passive-Houses+%283%29.pdf

Additional field studies of cold-climate heat pump performance are known to be currently underway in Massachusetts and New York, but no information has been published relating to their scope or results.

Briefly, the published field-testing reports show a significant drop in actual, cold-climate heat pump performance compared to manufacturer efficiency ratings. Many of the reports showed efficiencies that were 20 to 30 percent lower than manufacturer ratings. Identified causes included excessive compressor cycling under part-load conditions, sub-optimal defrost operation, and airflow restrictions in indoor units. Some of the efficiency differences can also be attributed to manufacturer ratings that are based on weather data for USDOE Climate Zone 4, which covers much of the warmer, mid-Atlantic region south of New York.

These technical notes and comments are also based on resources from Argonne National Laboratory (GREET model), the National Renewable Energy Laboratory (NREL), and the United Nations Intergovernmental Panel on Climate Change (UN IPCC) 2019 guidance update on life-cycle analysis of fuels and power generation.

INITIAL DISCUSSION OF DATA PUBLISHED IN REFERENCES

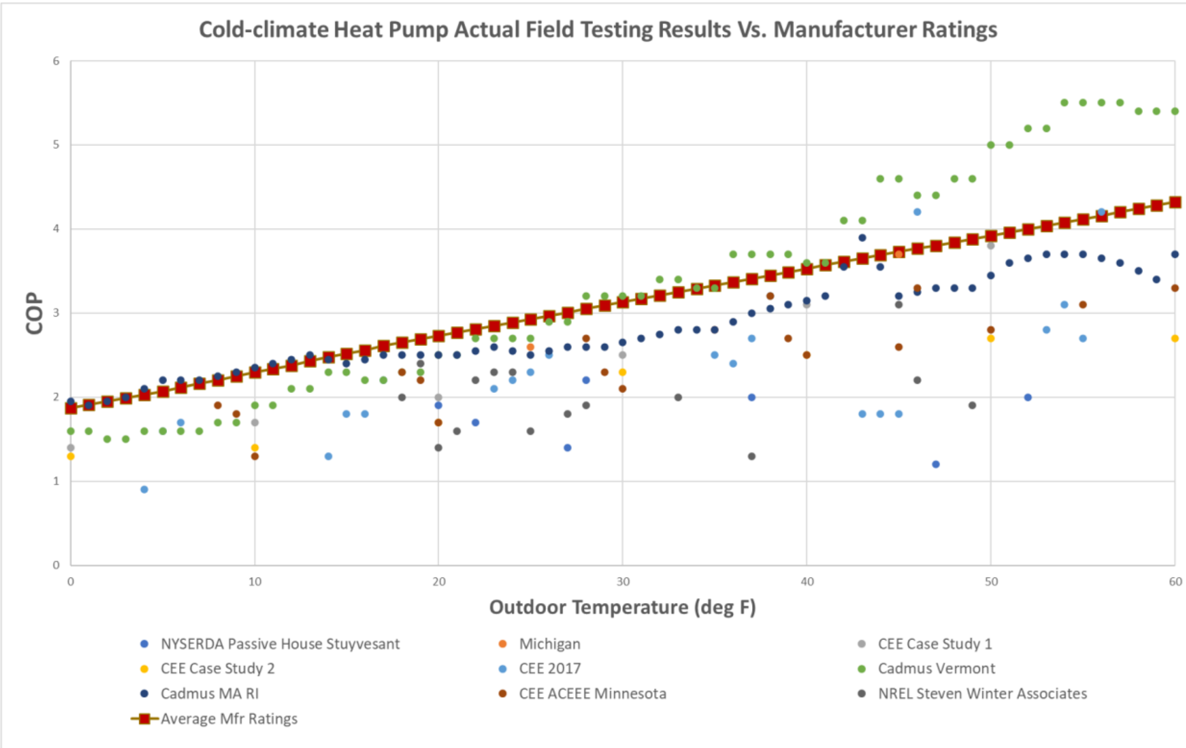


Figure 1. Cold-climate Heat Pump Actual Field-Testing Results vs. Manufacturer Ratings

Figure 1 above shows data for actual field test performance vs. outdoor temperature, as reported by the multiple reports used as references for these technical notes. The red data points are manufacturer ratings for the most commonly used heat pump equipment monitored during field testing. Further details on actual heat pump testing results are provided later in this document.

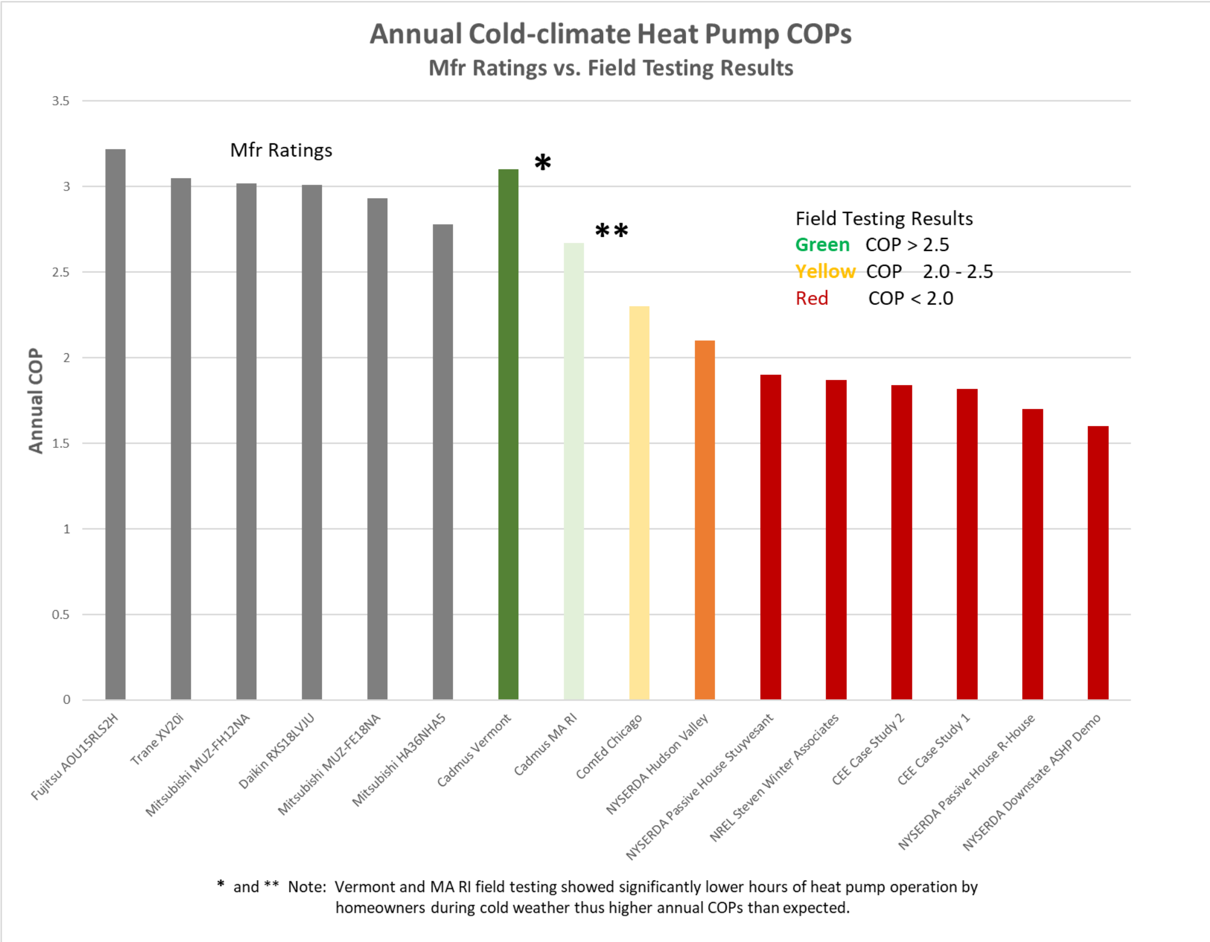


Figure 2. Annual Cold-climate Heat Pump COPs – Manufacturer Ratings vs. Field Testing Results

Figure 2 above shows annual, cold-climate heat pump COP data as published by the references used for these technical notes. The summary conclusion is that, especially if the lower COP figures, obtained from field testing, are combined with the use of marginal/non-baseload carbon intensity figures for power generation (instead of average grid mix figures), plus life-cycle analysis of natural gas used for power generation, the GHG savings of cold-climate heat pumps, compared to traditional oil-fired systems, are significantly diminished compared to popular claims by electrification proponents. Further details are provided later in this document.

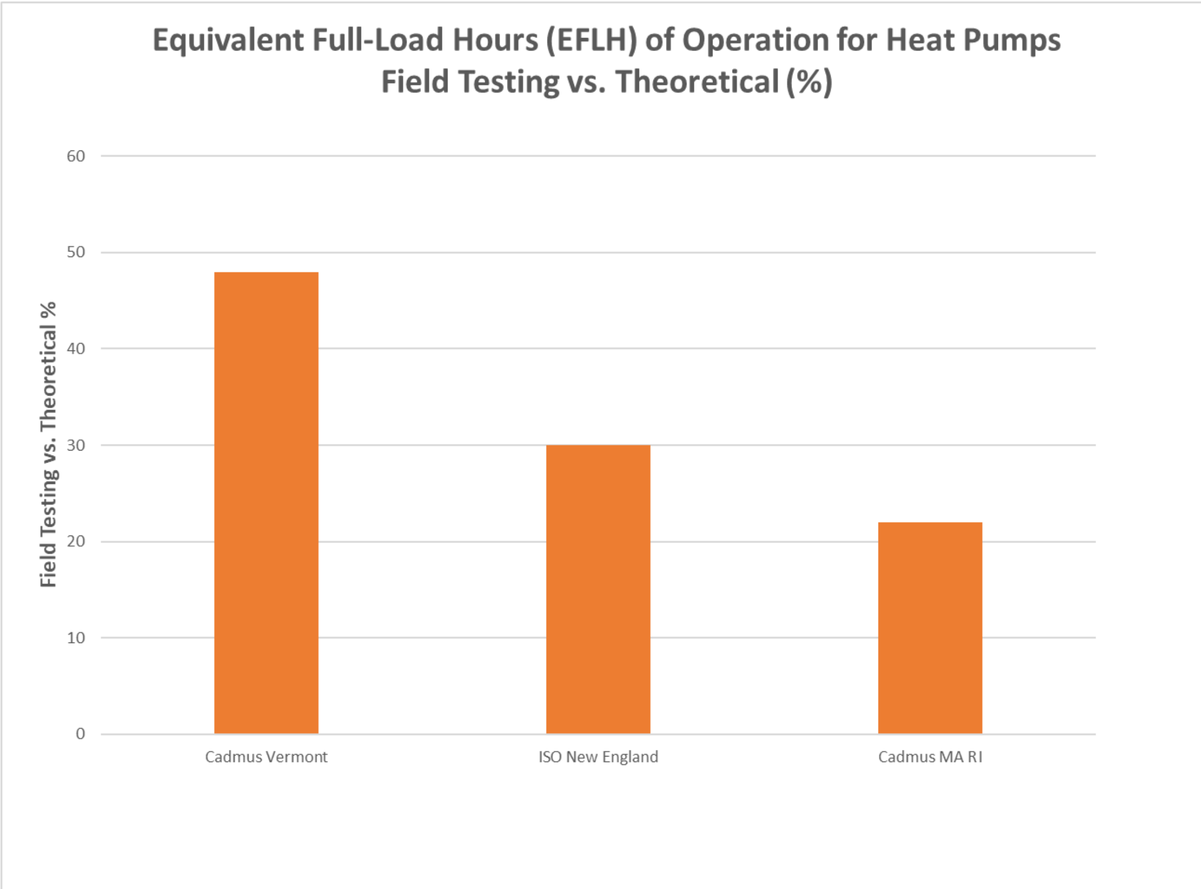


Figure 3. Equivalent Full-load Hours of Operation for Heat Pumps – Field Testing vs. Theoretical (%)

Several of the references for these technical notes addressed the issue of homeowner utilization of heat pumps during the heating season. Especially in New England, there was a notable under-utilization of heat pumps during the winter, with operating hours often in the range of 20 to 50% of technical potential. Further details are provided later in this document.

USE OF MARGINAL EMISSION RATES IN EVALUATION OF ELECTRIFICATION MEASURES

A recent publication by the Rocky Mountain Institute (RMI) states that a growing number of environmental organizations, when evaluating the emissions impacts of changes to grid loads or power production, "have been mis-applying average emissions factors to estimate the impact of environmental decisions. To protect against this mistake, the correct way to measure the impact of environmental decisions is to use *marginal* emissions factors. Marginal emissions factors measure the actual environmental consequences of taking different potential actions on the power grid."

The use of average grid mix figures has unfortunately become pervasive among electrification advocates in the Northeast. Average grid mix figures result in a severe underestimation of increases in CO2 emissions that would result from implementation of electrification measures.

See additional details in the informative RMI document entitled, On the Importance of Marginal Emissions Factors for Policy Analysis, which is available at https://rmi.org/combating-climate-change-measuring-carbon-emissions-correctly/ and also attached as an appendix at the end of this document.

See also https://www.watttime.org/app/uploads/2019/03/Automated-Emissions-Reduction-Primer_RMI-Validation_June2017.pdf and https://www.watttime.org/marginal-emissions-methodology/ for multiple additional references on the use of marginal emission rates for energy analysis. WattTime is a new, not-for-profit organization, and subsidiary to the Rocky Mountain Institute, which collects and disseminates hourly, real-world data on grid performance to enable informed, environmentally responsible electricity choices by large customers.

USE OF LIFE-CYCLE ANALYSIS OF ENERGY RESOURCES

It is of critical importance to use life-cycle analysis for energy policymaking. Onsite-based emissions evaluations generally fail to realistically address the real-world performance of the power grid. Argonne National Laboratory has been the host administrator of the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model for many years. The GREET model is a highly respected tool for evaluating the life-cycle characteristics of energy resources. The United Nations Intergovernmental Panel on Climate Change (UN IPCC) has issued a series of updates to its comprehensive documentation relating to evaluation of energy resources.

Both GREET and IPCC provide clear guidance on the evaluation of upstream emissions of energy resources. Notably, both have recently addressed the problem of methane leakage in compounding the environmental impact of natural gas, including that used for power generation. New York energy policymakers are strongly encouraged to join the international community in recognizing and quantifying the environmental impact of methane leakage on the carbon intensity of electrification technologies.

The two major reference sources for life-cycle analysis used in the preparation of these notes, including the Argonne National Laboratory GREET 2021 model, as well as the recent United Nations Intergovernmental Panel on Climate Change (IPCC) 2019 update report on guidance for life-cycle assessment protocols, have correctly addressed the environmental characteristics of natural gas used for power generation. Both the GREET and IPCC references incorporate a methane leakage rate of approximately 0.7% of the volume of natural gas used for power generation. This accounts for methane loss during natural gas production and high-pressure transmission directly to power plants, but not through any local distribution piping.

If a 100-year timeframe is used for analysis (GHG factor for NG = 25 compared to CO2), the 0.7% methane leakage rate results in about a 9 percent increase in the carbon intensity of natural gas that reaches the power plant. If a 20-year timeframe is used, however, for analysis (GHG factor for NG = 84 compared to CO2), the 0.7% methane leakage rate results in about a 20+ percent increase in the carbon intensity of natural gas used for power generation. There is growing support, and mandate in New York, for the use of 20-year greenhouse gas analysis since that reflects the timeframe that is now perceived as necessary for addressing climate change.

Combined with the impact of an approximate 10% increase in carbon intensity resulting from direct CO2 emissions during natural gas production and high-pressure transmission, the CO2e emissions characteristic of natural gas used for power generation is approximately 30% higher than the 117 lb/MMBTU onsite emissions figure frequently used by electrification proponents, thus approximately 152 lb/MMBTU.

GREET 2021 model figures are used for other fuel-based options included in the analysis presented here. The GREET figure of 185 lb/MMBTU (20 year LCA basis) is used for natural gas in residential and commercial heating, thus reflecting the additional methane losses that are incurred in local distribution networks. The GREET figure of 223 lb/MMBTU (20 year LCA) is used for distillate heating oil. GREET 2021 figures of 29 lb/MMBTU and 73 lb/MMBTU are used respectively for biodiesel produced from waste feedstock and virgin soy oil.

National Renewable Energy Laboratory (NREL) figures are used for evaluating renewable natural gas (RNG) and wind power. Carbon intensity data for RNG are sparse in availability, but indicate that RNG can have approximately the same sustainability values as has been documented for biodiesel. NREL carbon intensity figures for wind likewise are sparse.

ACCOUNTING FOR TRANSMISSION AND DISTRIBUTION LINE LOSSES IN ANALYSIS OF GRID IMPACTS OF ELECTRIFICATION

When the electrical load increases in a building, the corresponding increase in necessary power generation will be greater due to line losses that occur between the powerplant and end-use sites. The average line loss in transmission and distribution networks will usually be somewhere in the range of 8 percent here in the northeastern US. This factor must be included in analyses of electrification and renewable power generation to maintain accuracy of results. The practical consideration is that the MW amount of renewable power generation necessary to serve an increased grid load will be measurably greater than the load itself. The EPA AVERT model incorporates an automatic, built-in calculation of approximately 8% line losses. It is noted here, however, that since line losses are an I^2R issue, with losses proportional to the square of the current flow rate, thus not just a linear relationship, the incremental losses for increased grid loads during peak periods will typically be in the mid-teen percentage range, with the exact figure defined as the calculus derivative of the governing, line-loss mathematical equation. The significant policy impact of increased line losses during peak grid load conditions, due to electrification, needs to be recognized and addressed by energy policymakers.

POWER GRID ANALYSIS SOFTWARE

I used USEPA AVERT (AVoided Emissions and geneRation Tool) software to do an hourly analysis of grid impacts from residential and commercial heat pumps and to calculate required capacities of renewable power, including offshore wind, onshore wind, and utility-scale solar that would be necessary to meet expected New York heating loads using heat pumps.

See https://www.epa.gov/avert and https://www.epa.gov/avert/avert-overview-0 for more information about the AVERT program.

USEPA's AVERT software performs deep analysis using marginal emission rates, rather than average grid mix values, which are incorrectly used by many energy policymakers in the northeastern United States (see Appendix article by the Rocky Mountain Institute). AVERT analyzes how power plants would increase/decrease their output in response to grid load changes, and what the corresponding changes in fuel use and emissions would occur. AVERT software uses the EPA national air markets database, which incorporates hourly efficiency and emissions performance data for all power plants in the United States over 25 MW capacity.

AVERT software can calculate the hourly, regional marginal impact of reductions in grid load due to energy efficiency measures, as well as increases in grid load due to intentional load-building measures such as heat pumps and electric vehicles. AVERT software also can predict the hourly, marginal impact of renewable generation by resources such as solar PV and wind power, using hourly weather data. AVERT also predicts local changes in power generation output levels by individual generating plants within a specified region.

The AVERT 3.1 software version released just this past October also incorporates direct linkage with USEPA Co-Benefits Risk Assessment (COBRA) public health and Sparse Matrix Operator Kernel Emissions (SMOKE) air quality input software packages. This allows for direct modeling of public health and air quality impacts (NOx/SOx etc.) of changes in load or generation output within a regional grid. This enables the evaluation of air quality deterioration in environmental justice communities located adjacent to fossil-fired power plants as grid loads increase due to electrification, or improvements through implementation of renewable power generation.

AVERT spreadsheets are somewhat bulky, with typically close to 9,000 rows in height and many columns wide, but are nevertheless relatively user-friendly. Ancillary spreadsheet analysis of grid loads, using digital, hourly (8760 hours per year) weather data and heat pump performance formulas, can be easily copied into AVERT spreadsheets to yield highly informative, power generation and emissions outputs. New York energy policymakers are encouraged to use AVERT software if they are not already doing so.

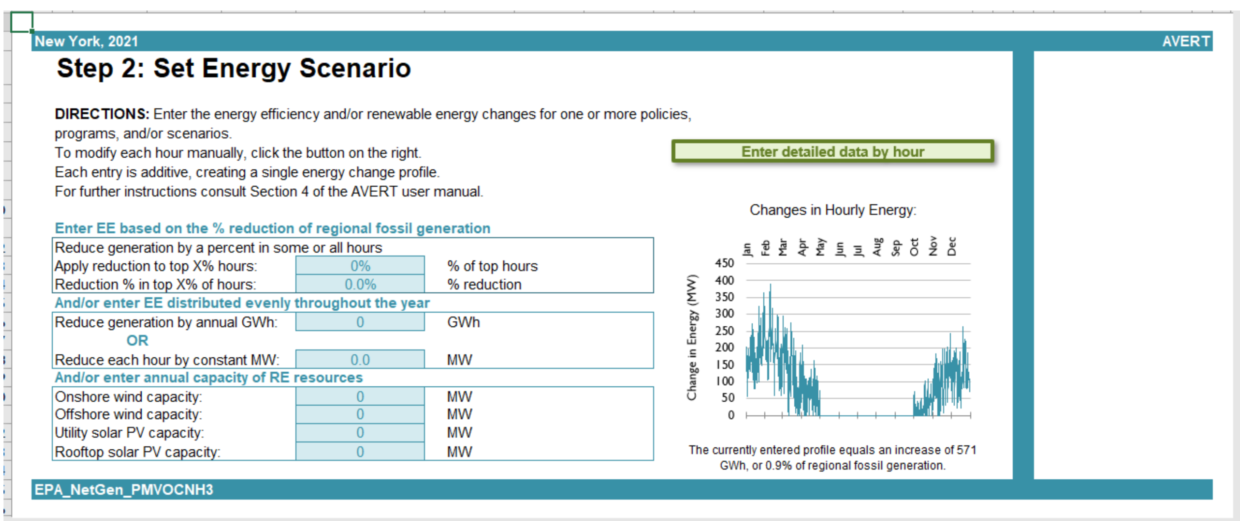


Figure 4. Example data input page for USEPA AVERT software

The screenshot shown above in Figure 4 shows an initial graph of monthly grid loads that would be triggered by implementation of residential and commercial heat pumps in New York. The AVERT program also allows for specification of renewable power capacities that might offset increasing grid loads.

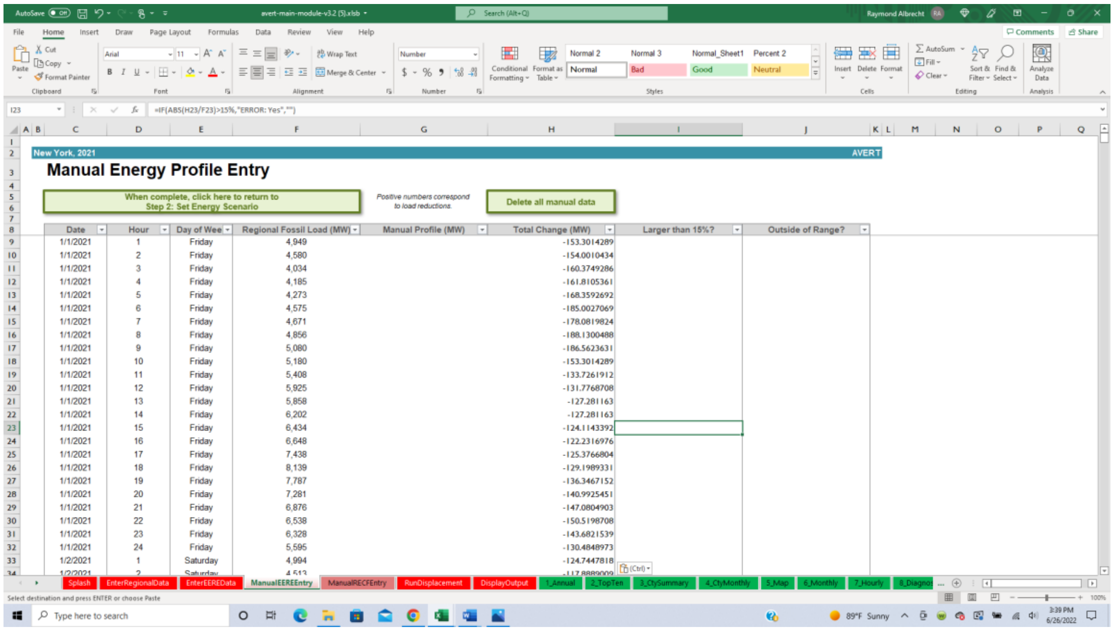
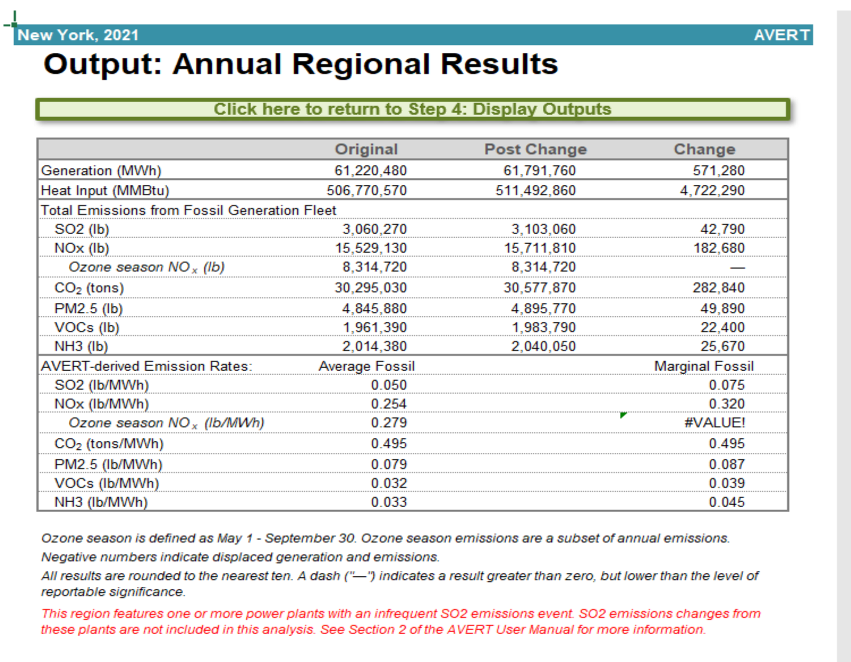


Figure 5. Screenshot of USEPA AVERT software – manual input of grid load data

The AVERT software incorporates the manual input of MW grid load values, based on calculated heating loads, heat pump COPs, and resulting site electrical load increases. The software then calculates impacts on power plant generation and CO2 emissions, as well as other pollutants such as NOx, SOx and PM2.5 particulates.



New York, 2021 AVERT

Output: Annual Regional Results

Click here to return to Step 4: Display Outputs

	Original	Post Change	Change
Generation (MWh)	61,220,480	61,791,760	571,280
Heat Input (MMBtu)	506,770,570	511,492,860	4,722,290
Total Emissions from Fossil Generation Fleet			
SO2 (lb)	3,060,270	3,103,060	42,790
NOx (lb)	15,529,130	15,711,810	182,680
Ozone season NO_x (lb)	8,314,720	8,314,720	—
CO_2 (tons)	30,295,030	30,577,870	282,840
PM2.5 (lb)	4,845,880	4,895,770	49,890
VOCs (lb)	1,961,390	1,983,790	22,400
NH3 (lb)	2,014,380	2,040,050	25,670
AVERT-derived Emission Rates:	Average Fossil		Marginal Fossil
SO2 (lb/MWh)	0.050		0.075
NOx (lb/MWh)	0.254		0.320
Ozone season NO_x (lb/MWh)	0.279		#VALUE!
CO_2 (tons/MWh)	0.495		0.495
PM2.5 (lb/MWh)	0.079		0.087
VOCs (lb/MWh)	0.032		0.039
NH3 (lb/MWh)	0.033		0.045

Ozone season is defined as May 1 - September 30. Ozone season emissions are a subset of annual emissions.
Negative numbers indicate displaced generation and emissions.
All results are rounded to the nearest ten. A dash ("—") indicates a result greater than zero, but lower than the level of reportable significance.
This region features one or more power plants with an infrequent SO2 emissions event. SO2 emissions changes from these plants are not included in this analysis. See Section 2 of the AVERT User Manual for more information.

Figure 6. Screenshot of AVERT summary output page showing annual generation and emissions impacts.

As shown in Figure 6 above, AVERT software produces an array of output tables and graphs ranging from hourly to annual figures. The information can then be further processed to evaluate the environmental characteristics of changes to grid loads or generation outputs.

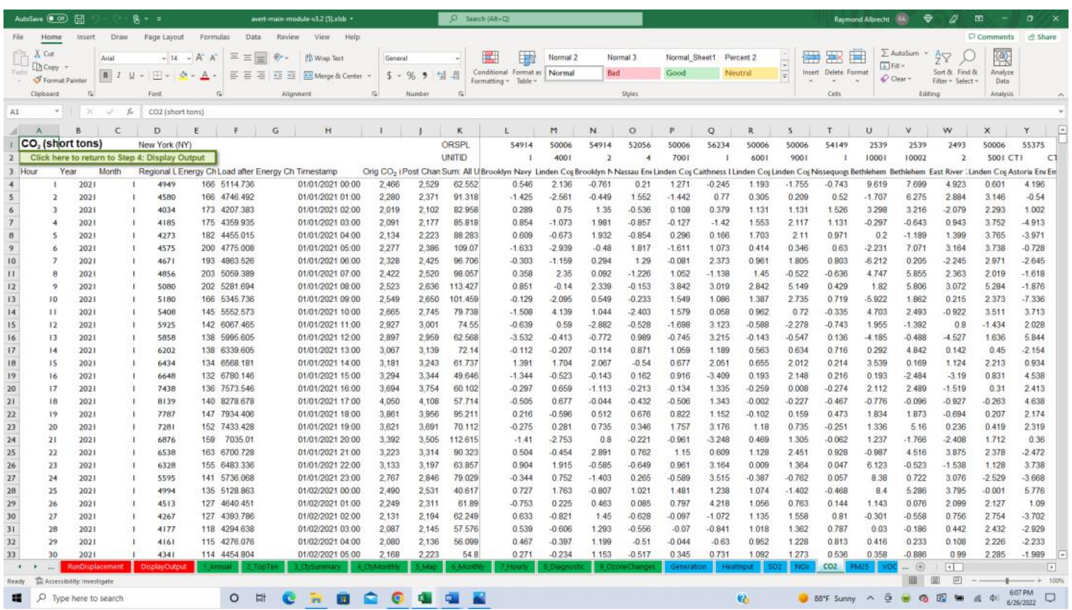
Generation (MW) New England (NE)

Click here to return to Step 4: Display Output

									ORSPL	58054	1595	55126	55126	55317	55149	56047	54907
									UNITID	ST01	4	CT01	CT02	11	LRG2	1	1
Hour	Year	Month	Regional L	Energy Ch	Load after Energy Ch	Timestamp	Orig Gen (	Post Chan	Sum: All U	Burgess Bic	Kendall Gr	Milford Pov	Milford Pov	Fore River	Lake Road (	CPV Towa	MIT Centr
1	2019	1	2259	1,652	3910.919	01/01/2019 00:00	2,252	3,932	1680.086	1.177	15.183	31.805	30.373	48.671	13.685	16.786	-0.897
2	2019	1	2288	1,652	3939.919	01/01/2019 01:00	2,281	3,953	1671.784	1.107	12.635	32.832	32.017	50.472	9.373	13.88	-1.166
3	2019	1	1944	1,498	3441.726	01/01/2019 02:00	1,938	3,445	1506.605	0.259	27.161	39.047	30.049	14.466	23.499	42.516	-2.135
4	2019	1	1879	1,448	3327.018	01/01/2019 03:00	1,874	3,320	1445.271	-1.702	30.659	34.215	35.429	5.892	28.018	47.653	-3.517
5	2019	1	1781	1,244	3024.919	01/01/2019 04:00	1,778	3,012	1233.478	-2.359	26.666	33.931	29.331	-14.675	35.82	51.917	-4.344
6	2019	1	1917	1,059	2976.402	01/01/2019 05:00	1,912	2,972	1059.843	-2.27	24.343	26.449	24.19	-6.853	26.897	38.558	-3.049
7	2019	1	2119	840	2959.374	01/01/2019 06:00	2,110	2,957	847.649	-2.337	16.266	19.244	14.552	-4.965	18.784	23.098	-1.841
8	2019	1	2201	812	3013.08	01/01/2019 07:00	2,193	3,002	809.47	-1.802	9.568	20.659	8.062	-6.425	19.769	22.993	-1.993
9	2019	1	2471	762	3232.892	01/01/2019 08:00	2,469	3,221	751.425	-2.262	12.232	17.54	11.142	23.524	9.864	17.605	-1.835
10	2019	1	2585	696	3281.418	01/01/2019 09:00	2,587	3,269	681.7	-4.347	8.473	16.756	8.087	11.175	13.911	19.563	-3.569
11	2019	1	2535	691	3226.034	01/01/2019 10:00	2,535	3,214	678.841	-3.715	10.385	17.41	11.112	14.819	12.411	16.443	-2.711
12	2019	1	2402	696	3098.418	01/01/2019 11:00	2,398	3,088	690.057	-0.462	10.929	17.98	8.341	24.219	8.756	12.084	-0.582
13	2019	1	2422	863	3285.225	01/01/2019 12:00	2,419	3,273	854.16	-0.596	13.278	17.522	8.945	32.854	7.434	20.611	-1.208

Figure 7. Screenshot of AVERT output page showing hourly changes to individual power plant MW generation outputs

As shown in Figure 7 above, AVERT software yields estimates of hourly changes to generation output and emissions by individual power plants. This information helps to identify what environmental justice communities might be affected by increased emissions that result from grid load growth due to electrification programs, when not sufficiently offset by new, renewable power generation.


CO_2 (short tons) New York (NY)

Click here to return to Step 4: Display Output

									ORSPL	54914	50006	54914	52056	50006	56234	50006	50006	54149	2539	2539	2493	50006	55375
									UNITID	1	4001	2	4	7001	1	6001	9001	1	10001	10002	2	5001	CT1
Hour	Year	Month	Regional L	Energy Ch	Load after Energy Ch	Timestamp	Orig CO_2 (	Post Chan	Sum: All U	Brooklyn Navy	Linden Cog	Brooklyn N	Nassau Ene	Linden Cog	Caithness L	Linden Cog	Linden Cog	Nissequogu	Bethlehem	Bethlehem	East River	Linden Cog	Astoria Ene
1	2021	1	4949	166	5114.736	01/01/2021 00:00	2,466	2,529	62.552	0.546	2.136	-0.761	0.21	1.271	-0.245	1.193	-1.755	-0.743	9.619	7.699	4.923	0.601	4.196
2	2021	1	4580	166	4746.492	01/01/2021 01:00	2,280	2,371	91.318	-1.425	-2.561	-0.449	1.552	-1.442	0.77	0.305	0.209	0.52	-1.707	6.275	2.884	3.146	-0.54
3	2021	1	4034	173	4207.383	01/01/2021 02:00	2,019	2,102	82.958	0.289	0.75	1.35	-0.536	0.108	0.379	1.131	1.131	1.526	3.298	3.216	-2.079	2.293	1.002
4	2021	1	4185	175	4359.935	01/01/2021 03:00	2,091	2,177	85.818	0.854	-1.073	1.981	-0.857	-0.127	-1.42	1.553	2.117	1.131	-0.297	-0.643	0.943	3.752	-4.913
5	2021	1	4273	182	4455.015	01/01/2021 04:00	2,134	2,223	88.283	0.609	-0.673	1.932	-0.854	0.296	0.166	1.703	2.11	0.971	0.2	-1.189	1.399	3.765	-3.971
6	2021	1	4575	200	4775.008	01/01/2021 05:00	2,277	2,386	109.07	-1.633	-2.939	-0.48	1.817	-1.611	1.073	0.414	0.346	0.63	-2.231	7.071	3.164	3.738	-0.728
7	2021	1	4671	193	4863.526	01/01/2021 06:00	2,328	2,425	96.706	-0.303	-1.159	0.294	1.29	-0.081	2.373	0.961	1.805	0.803	-6.212	0.205	-2.245	2.971	-2.645
8	2021	1	4856	203	5059.389	01/01/2021 07:00	2,422	2,520	98.057	0.358	2.35	0.092	-1.226	1.052	-1.138	1.45	-0.522	-0.636	4.747	5.855	2.363	2.019	-1.618
9	2021	1	5080	202	5281.694	01/01/2021 08:00	2,523	2,636	113.427	0.851	-0.14	2.339	-0.153	3.842	3.019	2.842	5.149	0.429	1.82	5.806	3.072	5.284	-1.876
10	2021	1	5180	166	5345.736	01/01/2021 09:00	2,549	2,650	101.459	-0.129	-2.095	0.549	-0.233	1.549	1.086	1.387	2.735	0.719	-5.922	1.862	0.215	2.373	-7.336
11	2021	1	5408	145	5552.573	01/01/2021 10:00	2,665	2,745	79.738	-1.508	4.139	1.044	-2.403	1.579	0.058	0.962	0.72	-0.335	4.703	2.493	-0.922	3.511	3.713
12	2021	1	5925	142	6067.465	01/01/2021 11:00	2,927	3,001	74.55	-0.639	0.59	-2.882	-0.528	-1.698	3.123	-0.588	-2.278	-0.743	1.955	-1.392	0.8	-1.434	2.028
13	2021	1	5858	138	5995.605	01/01/2021 12:00	2,897	2,959	62.568	-3.532	-0.413	-0.772	0.989	-0.745	3.215	-0.143	-0.547	0.136	-4.185	-0.488	-4.527	1.636	5.844
14	2021	1	6202	138	6339.605	01/01/2021 13:00	3,067	3,139	72.14	-0.112	-0.207	-0.114	0.871	1.059	1.189	0.563	0.634	0.716	0.292	4.842	0.142	0.45	-2.154
15	2021	1	6434	134	6568.181	01/01/2021 14:00	3,181	3,243	61.737	1.391	1.704	2.067	-0.54	0.677	2.051	0.655	2.012	0.214	3.539	0.169	1.124	2.213	0.934
16	2021	1	6648	132	6780.146	01/01/2021 15:00	3,294	3,344	49.646	-1.344	-0.523	-0.143	0.162	0.916	-3.409	0.193	2.148	0.216	0.193	-2.484	-3.19	0.831	4.538
17	2021	1	7438	136	7573.546	01/01/2021 16:00	3,694	3,754	60.102	-0.297	0.659	-1.113	-0.213	-0.134	1.335	-0.259	0.008	-0.274	2.112	2.489	-1.519	0.31	2.413
18	2021	1	8139	140	8278.678	01/01/2021 17:00	4,050	4,108	57.714	-0.505	0.677	-0.044	-0.432	-0.506	1.343	-0.002	-0.227	-0.467	-0.776	-0.096	-0.927	-0.263	4.638
19	2021	1	7787	147	7934.406	01/01/2021 18:00	3,861	3,956	95.211	0.216	-0.596	0.512	0.676	0.822	1.152	-0.102	0.159	0.473	1.834	1.873	-0.694	0.207	2.174
20	2021	1	7281	152	7433.428	01/01/2021 19:00	3,621	3,691	70.112	-0.275	0.281	0.735	0.346	1.757	3.176	1.18	0.735	-0.251	1.336	5.16	0.236	0.419	2.319
21	2021	1	6876	159	7035.01	01/01/2021 20:00	3,392	3,505	112.615	-1.41	-2.753	0.8	-0.221	-0.961	-3.248	0.469	1.305	-0.062	1.237	-1.766	-2.408	1.712	0.36
22	2021	1	6538	163	6700.728	01/01/2021 21:00	3,223	3,314	90.323	0.504	-0.454	2.891	0.762	1.15	0.609	1.128	2.451	0.928	-0.987	4.516	3.875	2.378	-2.472
23	2021	1	6328	155	6483.336	01/01/2021 22:00	3,133	3,197	63.857	0.904	1.915	-0.585	-0.649	0.961	3.164	0.009	1.364	0.047	6.123	-0.523	-1.538	1.128	3.738
24	2021	1	5595	141	5736.068	01/01/2021 23:00	2,767	2,846	79.029	-0.344	0.752	-1.403	0.265	-0.589	3.515	-0.387	-0.762	0.057	8.38	0.722	3.076	-2.529	-3.668
25	2021	1	4994	135	5128.863	01/02/2021 00:00	2,490	2,531	40.617	0.727	1.763	-0.807	1.021	1.481	1.238	1.074	-1.402	-0.468	8.4	5.286	3.795	-0.001	5.776
26	2021	1	4513	127	4640.451	01/02/2021 01:00	2,249	2,311	61.89	-0.753	0.225	0.463	0.085	0.797	4.218	1.056	0.763	0.144	1.143	0.076	2.099	2.127	1.09
27	2021	1	4267	127	4393.786	01/02/2021 02:00	2,131	2,194	62.249	0.633	-0.821	1.45	-0.628	-0.097	-1.072	1.135	1.558	0.81	-0.301	-0.558	0.756	2.754	-3.702
28	2021	1	4177	118	4294.638	01/02/2021 03:00	2,087	2,145	57.576	0.539	-0.606	1.293	-0.556	-0.07	-0.841	1.018	1.362	0.787	0.03	-0.186	0.442	2.432	-2.929
29	2021	1	4161	115	4276.076	01/02/2021 04:00	2,080	2,136	56.099	0.467	-0.397	1.199	-0.51	-0.044	-0.63	0.952	1.228	0.813	0.416	0.233	0.108	2.226	-2.233
30	2021	1	4341	114	4454.804	01/02/2021 05:00	2,168	2,223	54.8	0.271	-0.234	1.153	-0.517	0.345	0.731	1.092	1.273	0.536	0.358	-0.886	0.99	2.285	-1.989

Figure 8. Screenshot of AVERT output page showing hourly changes to individual power plant CO2 emission rates (lb/hr)

As shown in Figure 8 above, AVERT software also yields estimates of hourly changes to CO2 emissions from individual power plants. Such information is of key importance for the wholistic evaluation of environmental performance by a combined heating equipment-power grid system.

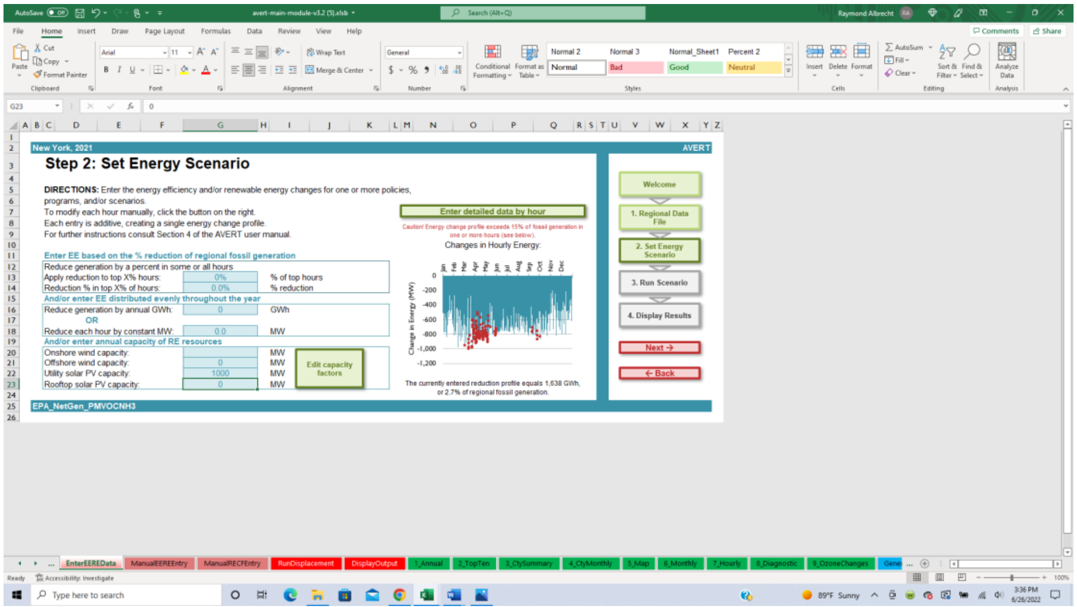


Figure 9. Screenshot of AVERT input page showing MW quantities of renewable power generation capacity selected for analysis.

As shown in Figure 9 above, AVERT software also allows for the specification of amounts of wind and solar generation resources. The software then yields an hourly output table for the entire year, which can then be combined with grid load data to determine whether sufficient renewable power has been generated to meet the demand of electrification technologies, and if not, the quantity of fuel-based generation that must still be operated.

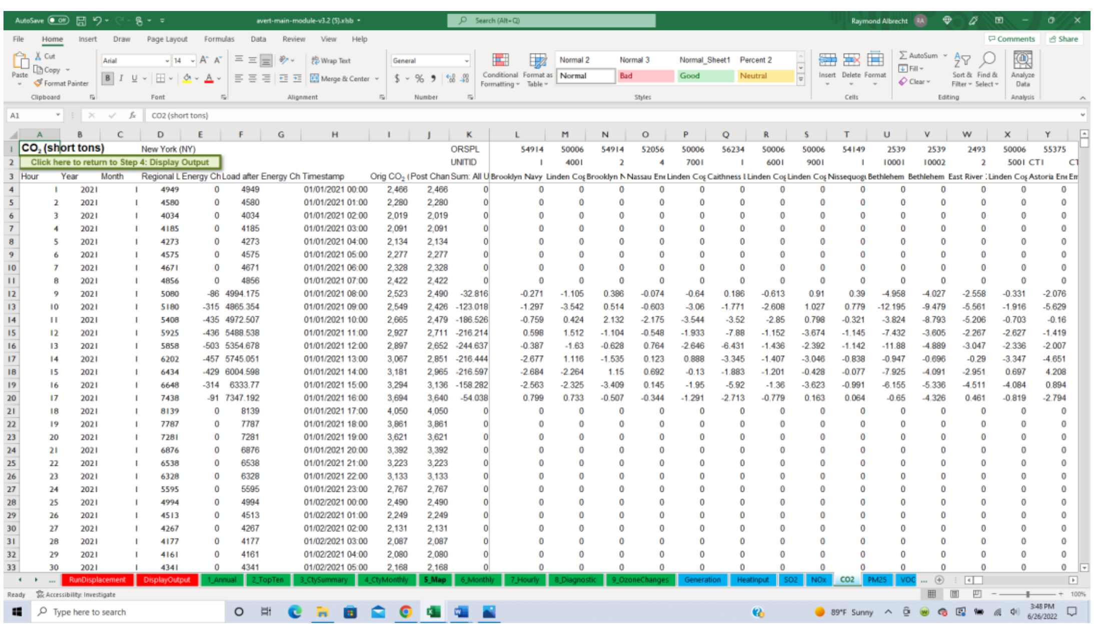


Figure 10. Screenshot of AVERT output page showing hourly values of solar power output plus impact on individual power plants.

As shown in Figure 10 above, AVERT software calculates the hourly production of wind and solar power systems based on a typical year of weather data. The software then allocates reductions in generation output to individual power plants. The output data can then be combined with heating and grid load data to determine how much fuel-fired power generation might still be necessary if sufficient renewable power generation capacity has yet to be constructed.

METHODOLOGY FOR HOURLY EVALUATION OF COMBINED HEAT PUMP PERFORMANCE AND NYISO GRID CARBON INTENSITY FOR RESIDENTIAL AND COMMERCIAL HEATING

These technical notes are based on an hourly, coincidental temporal analysis of heating loads and power grid performance. Digital weather data from Visual Crossing.com for Islip and Syracuse are used to model hourly heating loads in a representative single-family residential unit that would have a peak heating load of 32,000 Btu/hr at an outdoor temperature of 5 deg F. The described heating load formula is intended to be broadly representative for residential buildings located in New York. Specific heating loads for downstate and upstate (Central/Western) NYISO zones are determined by actual, historical weather data for the year 2021, and are reflective of their respectively warmer and cooler climates.

Temperature delta T values are determined using a base of 65 deg F as is customary for heating degree day analysis. Carbon intensities for common fuels including heating oil, natural gas, biodiesel and renewable natural gas are derived from the GREET 2021 model, as described earlier in this document. Heat pump COPs vs. outdoor temperature are determined through a formula based on the field test results included in the references described earlier.

Figure 11 below shows a screenshot of an Excel table that was created to perform the described hourly analysis of heating loads, grid performance, fuel/electricity input options, carbon intensities and resulting CO2 emission rates. The table includes input and output figures for the approximately 5000 hours that occur during the October through April heating season.

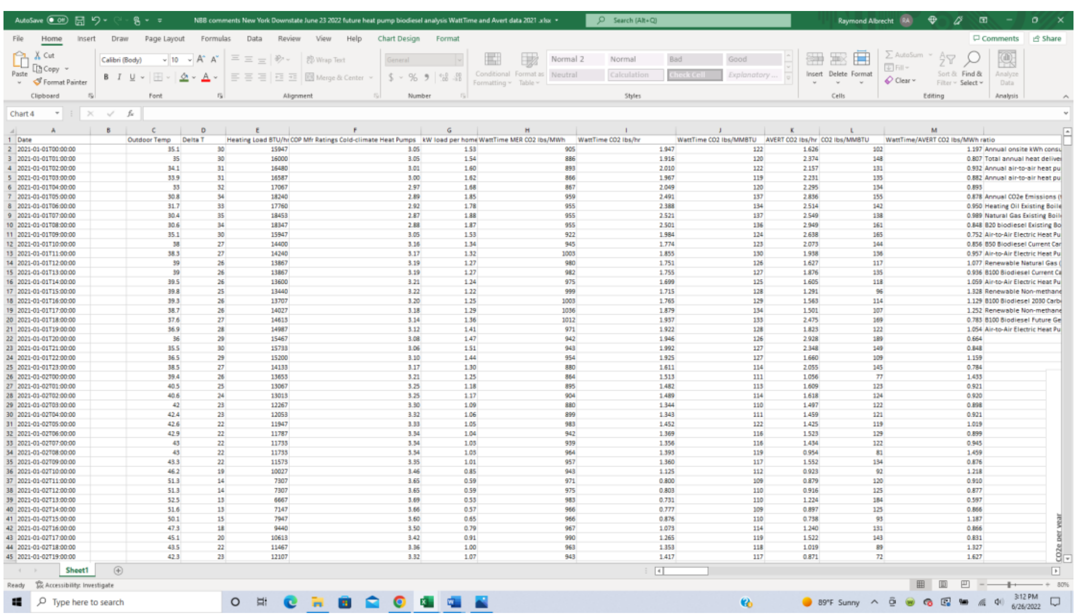


Figure 11. Screenshot of hourly heating system and power grid performance Excel analysis table.

After hourly heating loads and corresponding grid load increases have been determined, interim data from the Excel table are copied to the manual data input page of the AVERT software. The AVERT software then calculates generation and CO2 emissions changes, which are then transferred back to the Excel table to enable completion of the combined analysis.

WattTime hourly Marginal Emission Rates (MERs) in lbs CO2 per MWh for downstate and central/western NYISO zones were also used in the Excel table to evaluate the grid impact of heat pumps. WattTime data does not provide for analysis of impacts on individual power plants, but provides for a higher resolution analysis of geographical variations in carbon intensity between NYISO zones. While downstate and central/western NYISO zones have essentially the same MER characteristics for 90 percent of the heating season, the lower carbon intensities that do occasionally occur in central/western NYISO zones can make a modest but measurable difference in annual heat pump performance.

ANALYTICAL RESULTS AND TECHNICAL COMMENTS

Annual CO2e Emissions for Single-family Homes in New York

Figure 12 below shows annual CO2e emissions for a single-family home in downstate NYISO zones under several different technology options that are feasible by the year 2030. The downstate NYISO region, which extends from Long Island and New York City through the Hudson Valley, has approximately 5 million residential units plus a broad array of commercial, industrial and institutional buildings. Traditional fuel options include heating oil and natural gas. Renewable fuel options include biodiesel blends as well as renewable natural gas. Heat pump options include current air-to-air technology plus improved, future generation technology. The graph also includes scenarios for the existing grid plus options for partial and full-capacity renewable power generation for operation of heat pumps. It needs to be noted that the option for full-capacity renewable power generation, which would be difficult to achieve by the year 2030, and which is shown as a long-term goal, also includes the requirement for 1,300,000 MWh of battery storage to be sufficient for 48 hours of operation during periods of extreme cold temperature with low offshore wind and solar output.

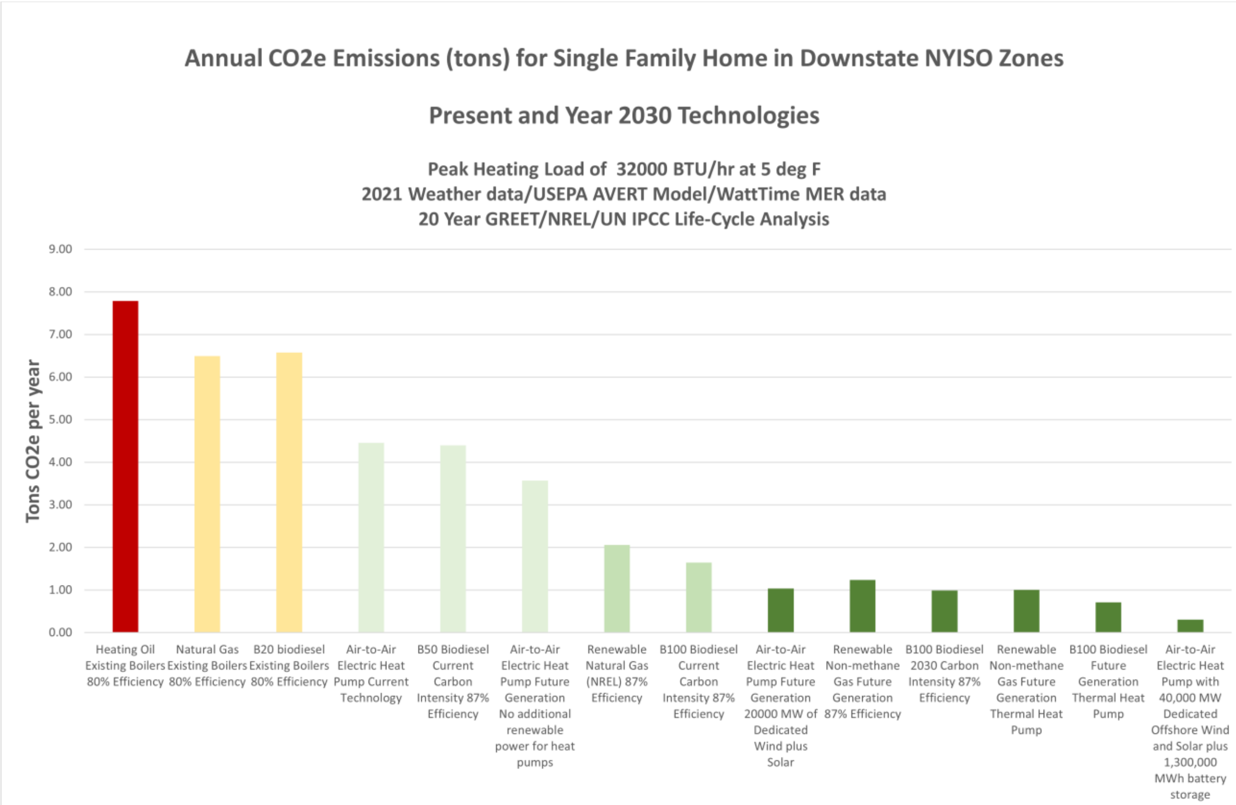


Figure 12. Annual CO2e Emissions for Single Family Homes in Downstate NYISO Zones.

The individual graph bars in Figure 12 show similar, moderate savings, compared to traditional heating oil and natural gas-fired boilers, for current heat pump technology and basic (e.g., B20) biodiesel blends. There is then a general declining trend in CO2e emissions as biodiesel concentrations increase to the 50 and 100 percent levels, and as dedicated, offshore wind plus utility-scale solar capacity growth to 20,000 MW, and then 40,000 MW, nameplate capacity is accomplished. Dedicated offshore wind plus utility-scale solar capacity of 20,000 MW would achieve CO2e savings for heat pumps of about 70 percent compared to heat pumps that use the existing grid, with an overall, seasonal carbon intensity that is approximately the same as for B100 biodiesel using an 87% efficient boiler. Dedicated renewable power capacity of 40,000 MW would provide for heat pump utilization during the peak heating periods of the winter, but would require approximately 1,300,000 MWh of battery storage to maintain continued grid operation for up to 48 hours during low wind and solar output conditions.

The graph also shows carbon intensity values for renewable fuel-fired, absorption heat pumps. Such heat pumps can achieve efficiency levels of 120 percent, depending on manufacturing design, with future increases expected.

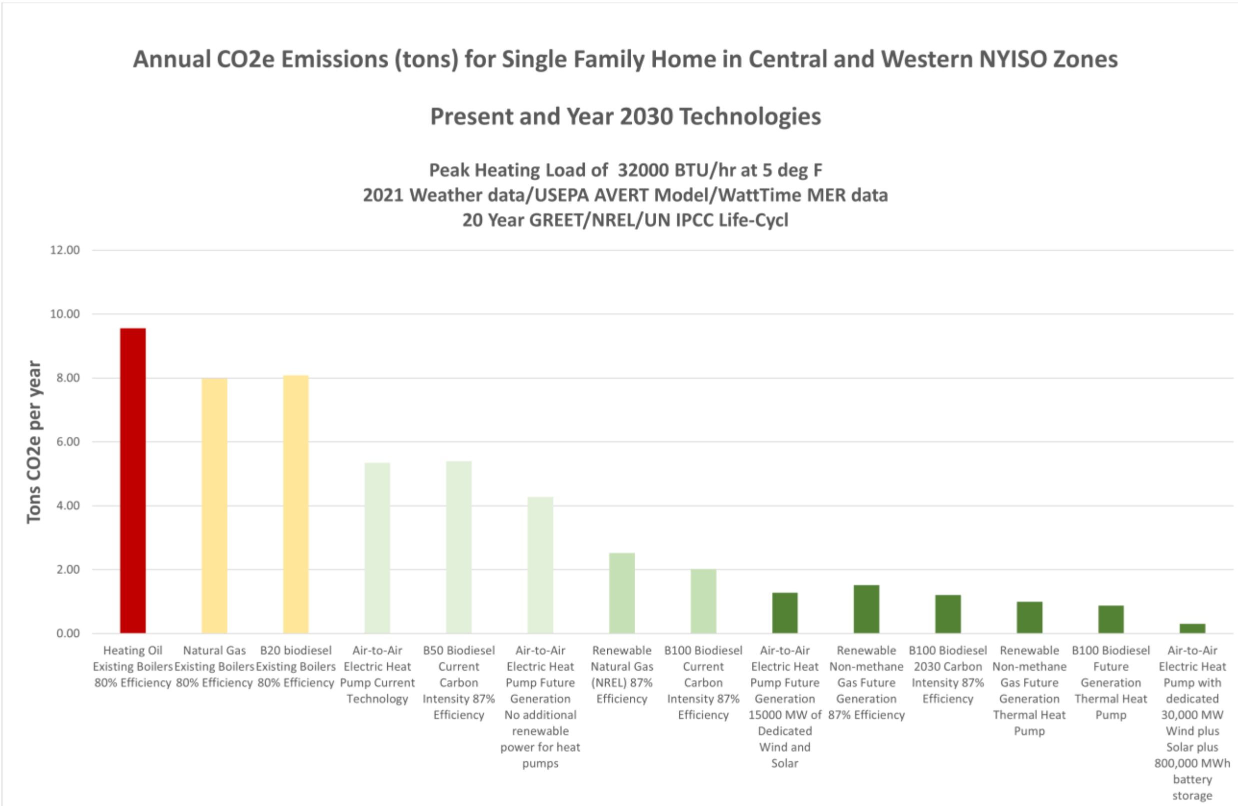


Figure 13. Annual CO2e Emissions for Single Family Homes in Central/Western NYISO Zones.

Figure 13 above shows corresponding annual CO2e emissions for a single-family home located in central and western NYISO zones. The central and western NYISO region has approximately 2 million residential units. Heating load levels are approximately 20 percent higher, and heat pump COPs are somewhat lower, due to the colder climate there. But seasonal marginal emission rates for power generation are about 10 percent lower than for downstate NYISO zones, thus offsetting part of the impact of colder temperatures. The relative order of merit among energy technology options remains essentially the same as for downstate NYISO zones.

Carbon Intensity of Fuel-fired and Heat Pump Options

Figure 14 below shows hourly carbon intensity vs. outdoor temperature for the most common of the energy options included in the previous graph for downstate NYISO zones. The data shown in medium green color illustrate that the carbon intensity of heat pumps can climb significantly during cold weather due to declining COP values. To note, the data points are time-weighted rather than load-weighted, thus the performance levels shown in the left half of the graph, during colder temperatures, are of greater significance re: energy consumption than data points in the right half of the graph.

Overall, the carbon intensity of B50 biodiesel blend is approximately equal to, or somewhat higher than, heat pumps during mild weather, but significantly lower than heat pumps during cold weather, which is when the grid is under greatest stress. This raises the question of what energy resource strategy would be most effective during cold weather. The carbon intensity of B100 biodiesel is lower than all other energy options throughout the entire temperature range.

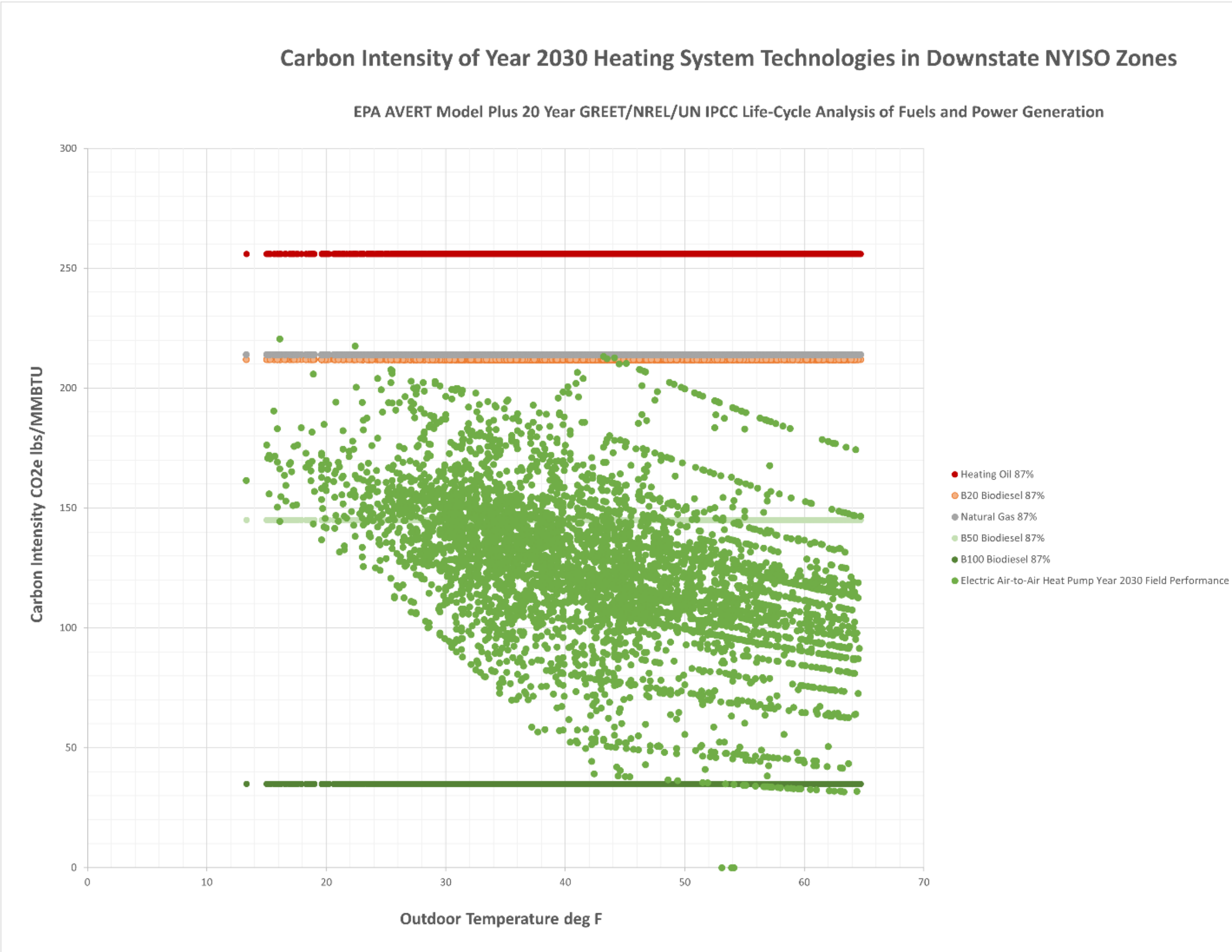


Figure 14. Existing, Time-weighted, Carbon Intensity (lbs CO2e per MMBTU) vs. Outdoor Temperature for Year 2030 Heating Technologies in Downstate NYISO Zones

Of particular note, there are wide variations in the carbon intensity for heat pumps at any given outdoor temperature, primarily due to the higher heat rates for power generation which occur during morning and evening peak periods. There is considerable merit to the argument that heat pump controls should be web-enabled and programmed to: 1) synchronize system operation with low-carbon intensity hours; and 2) switch to an alternate fuel source during hours of high carbon intensity on the grid.

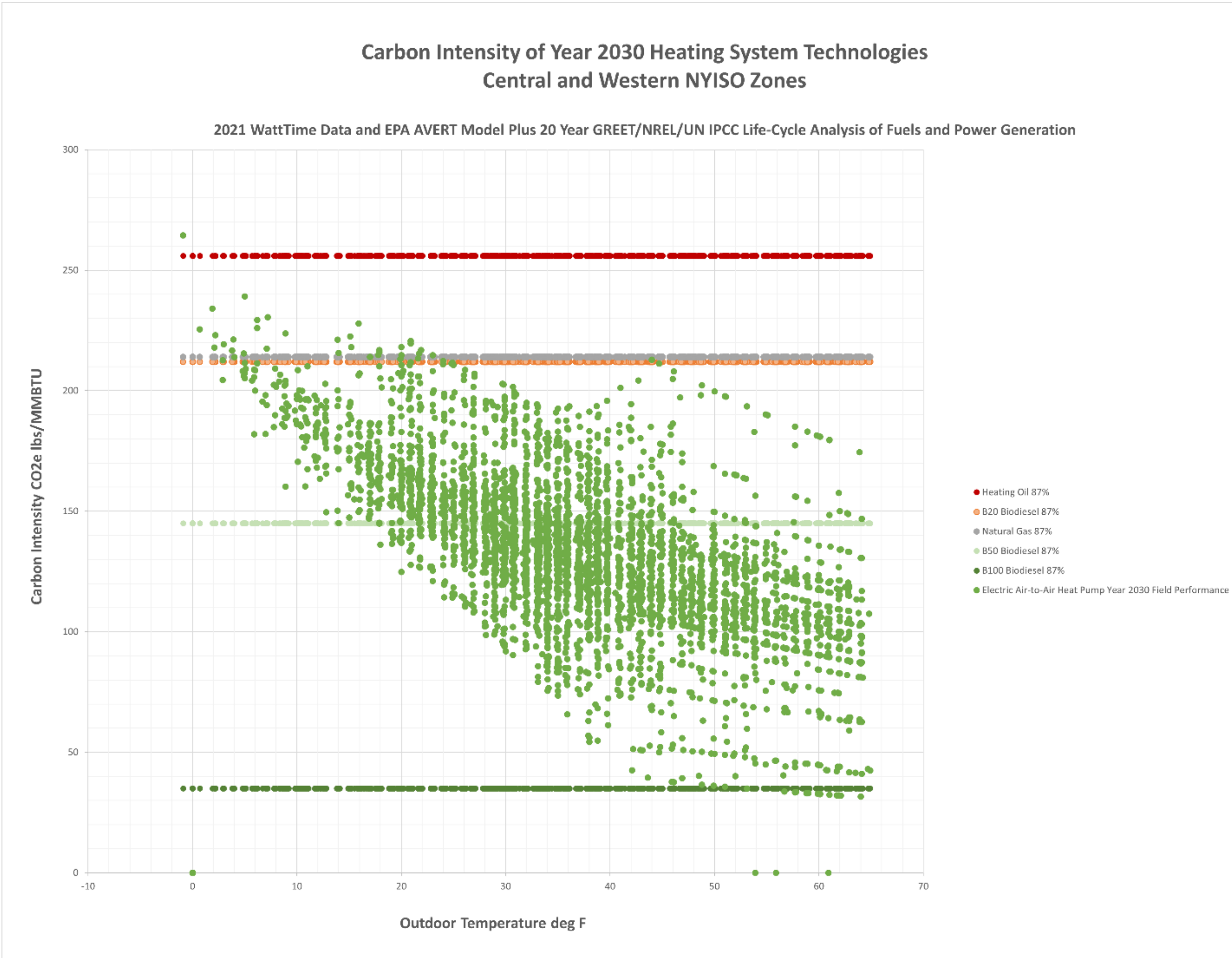


Figure 15. Existing, Time-weighted, Carbon Intensity (lbs CO2e per MMBTU) vs. Outdoor Temperature for Year 2030 Heating Technologies in Central and Western NYISO Zones

Figure 15 above shows existing hourly carbon intensity vs. outdoor temperature for the most common of the energy options included in Figure 13 for central and western NYISO zones. The graph is similar in appearance to Figure 12 (downstate NYISO zones) but extends to much lower temperatures due to the colder climate. During outdoor temperatures of 20 deg F and lower, the carbon intensity of heat pumps increases to nearly the same values for natural gas and B20 biodiesel blends. Additional conclusions from Figure 15 are that the carbon intensity of B50 biodiesel blend is lower than for heat pumps at outdoor temperatures lower than 30 deg F, and B100 remains the lowest carbon intensity option throughout the entire temperature range.

The scatter in carbon intensity data for heat pumps, with many data points indicating only very limited CO2 savings compared to conventional fossil fuels, again highlights the need for web-enabled, synchronization of heat pumps to coincide operation with low-carbon intensity grid hours.

The relative CO2e emissions shown in the graphs described above are applicable to both residential and small commercial heating systems. Biodiesel and heat pumps both offer alternative pathways to the end goal of carbon neutrality by 2050, but biodiesel offers the opportunity for immediate accomplishment of major CO2e savings through the use of B100, whereas heat pumps are dependent on the expansion of offshore wind capacity or imports of other forms of renewable power, sufficient to reach the margin of grid power load, before they can even start to become fully renewable thermal energy resources.

Increase in Grid Load Due to Electric Heat Pumps

Figure 16 below illustrates the grid load increase that would occur in downstate NYISO zones if there were full implementation of residential and commercial heat pumps. The analysis is based on the adoption of heat pumps by approximately 5 million residential units plus nearly all commercial buildings. The graph shows expected grid load increases based on the use of future generation heat pump technologies that use 20% less power than current cold-climate heat pump technologies.

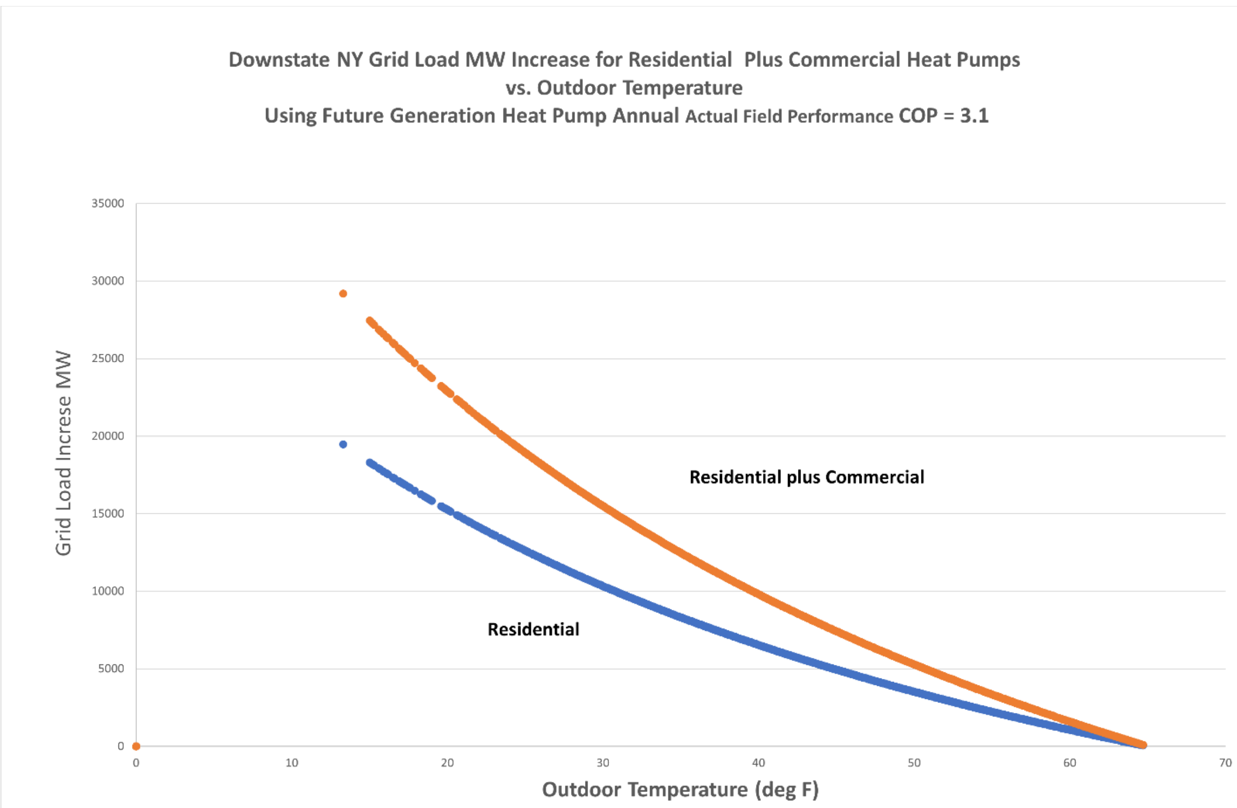


Figure 16. Grid Load Increase (MW) vs. Outdoor Temperature for Full Implementation of Residential and Commercial Heat Pumps in Downstate NYISO Zones

Figure 16 shows an estimated grid load growth of more than 25,000 MW for operation of residential and commercial heat pumps during peak winter conditions. The data are based on the presumption that whole-house heat pumps would be used with no fuel-fired back-up. Such grid load growth would be approximately triple the existing winter peak load in downstate NYISO zones.

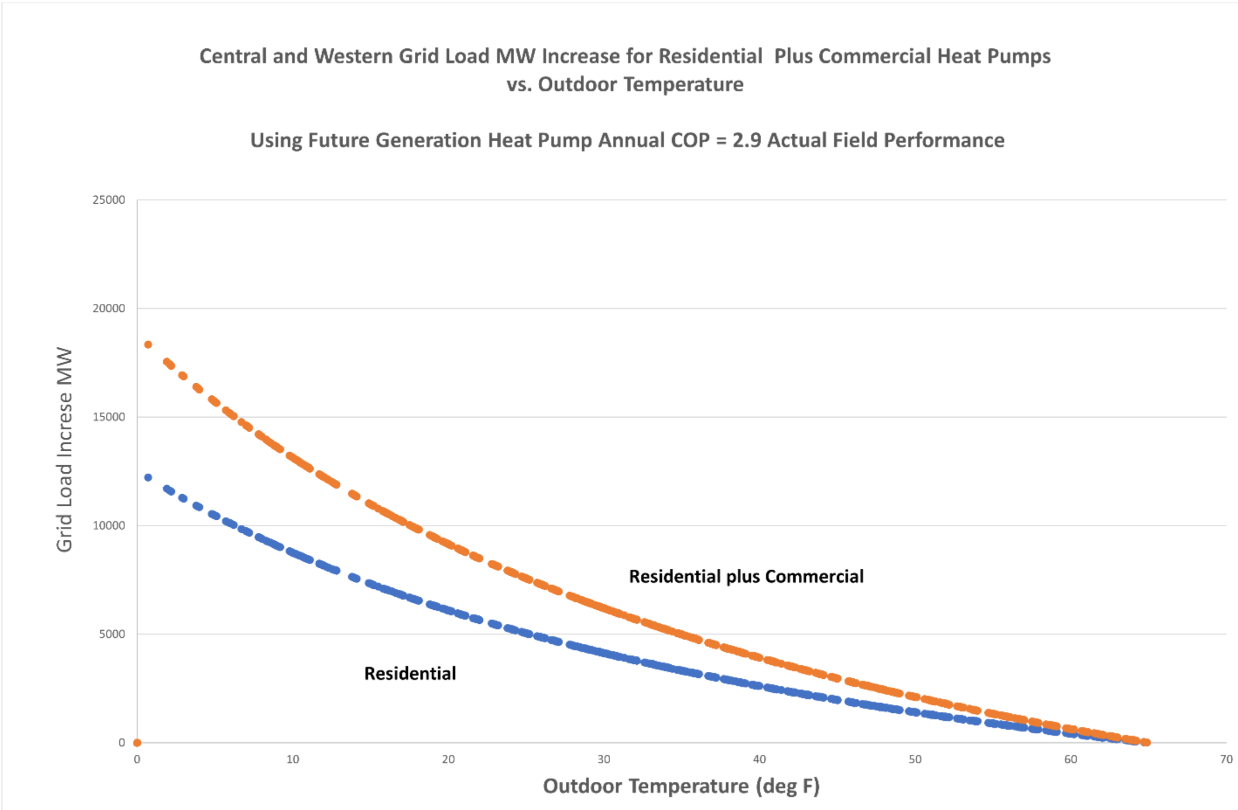


Figure 17. Grid Load Increase (MW) vs. Outdoor Temperature for Full Implementation of Residential and Commercial Heat Pumps in Central and Western NYISO Zones

Figure 17 above shows an estimated grid load growth of about 18,000 MW for operation of residential and commercial heat pumps during peak winter conditions. The data are based on the presumption that whole-house heat pumps would be used with no fuel-fired back-up. Such grid load growth would be approximately triple the existing winter peak load in central and western NYISO zones.

NEED FOR HIGHER LEVELS OF RENEWABLE POWER GENERATION BEFORE ELECTRIFICATION CAN ACHIEVE FULL ENVIRONMENTAL BENEFITS

Wind and solar projects planned for the next 10 to 20 years in New York, even if fully developed, will make a good start toward eliminating fossil generation for present grid loads, but will not provide the substantial growth in capacity necessary for heat pumps or EV growth.

The next graph shows the offshore wind capacity that would be required to meet the winter heating loads of cold-climate heat pumps for residential and commercial buildings in downstate NYISO zones. The blue bars represent monthly MWh consumption by residential and commercial heat pumps. The orange bars represent monthly MWh production by 20,000 MW of nameplate capacity offshore wind power. The gray bars represent MWh production by 20,000 MW of nameplate capacity solar power. Monthly MWh production figures are provided by the USEPA AVERT model based on historical weather data for the New York region.

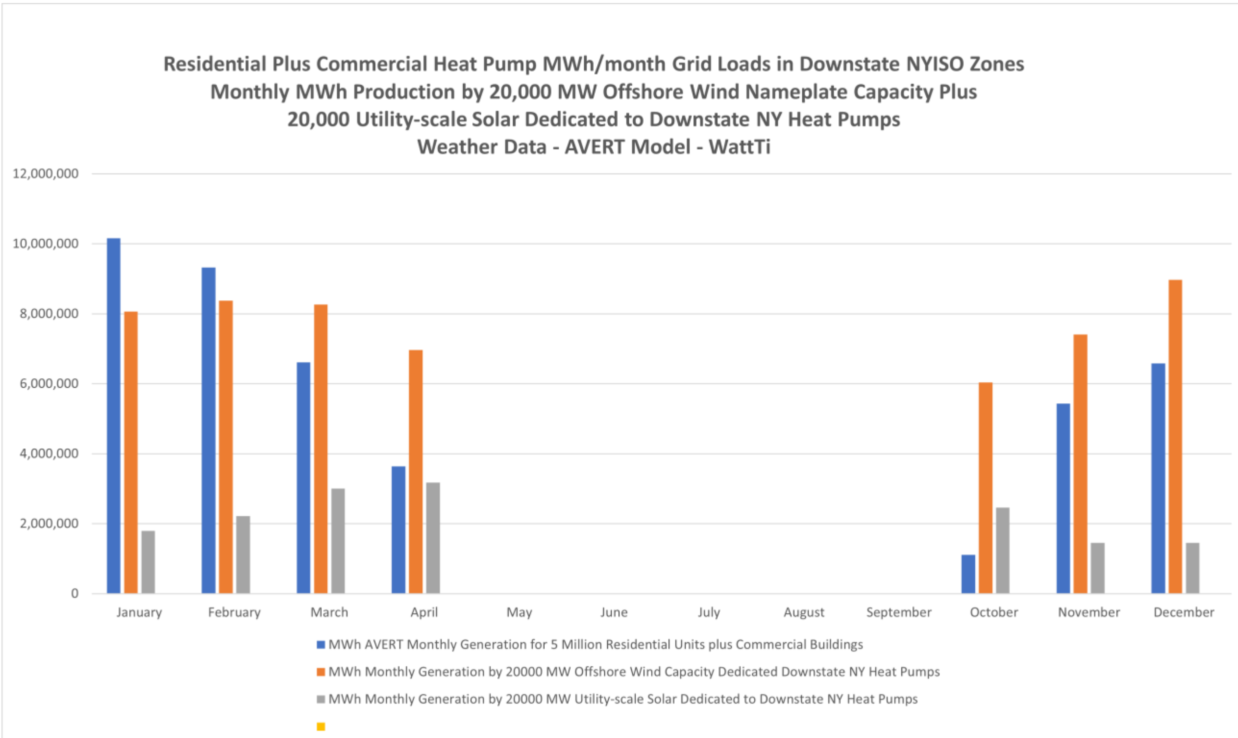


Figure 18. Monthly Grid Loads plus 20,000 MW Wind Capacity plus 20,000 Solar Capacity – Downstate

The graph indicates that an installed nameplate capacity of 20,000 MW of offshore wind plus 20,000 MW of solar power will approximately meet the needs of residential and commercial heat pumps in downstate NYISO zone during the coldest months of the heating season, assuming the nearly unlimited availability of battery storage. If it were possible to install this 20,000 MW of offshore wind capacity at a cost of $5 million per MW, and the 20,000 MWh of solar capacity at a cost of $3 million per MW, the total capital expense would be approximately $160 billion, which translates to something over $30,000 per family. If floating-type offshore wind platforms are required due to water depths of greater than 180 feet, an upward revision to the wind machine capital expense figure may become necessary.

For a downstate peak grid load of just over 25,000 MW for heating, as indicated in Figure 16, the required worst-case, 48 storage capacity, to enable continued operation during extended cold temperature and low windspeed conditions, would be approximately 1,200,000 MWh.

If utility-scale battery storage were to cost $200,000 per MWh capacity, the capital expense for battery storage would be approximately $240 billion, or approximately $45,000 per family, to cover the 48 hour storage during a wind drought. This figure may be subject to adjustment, however, based on battery material price increases or decreases which might occur as the wind and solar industries grow. Increased production volumes may contribute to economies of scale, which might provide downward pressure on costs. Increased volumes of mining and extraction of materials for batteries, on the other hand, could trigger higher prices due to supply shortages.

Recent capital cost analyses for residential heat pumps have centered on an approximate figure of $20,000 per onsite installation of residential or small commercial heat pumps. With the capital cost figures noted above for offshore wind capacity and battery storage, the total capital cost for full implementation of residential and commercial heat pumps in downstate New York could be just under $100,000 per family.

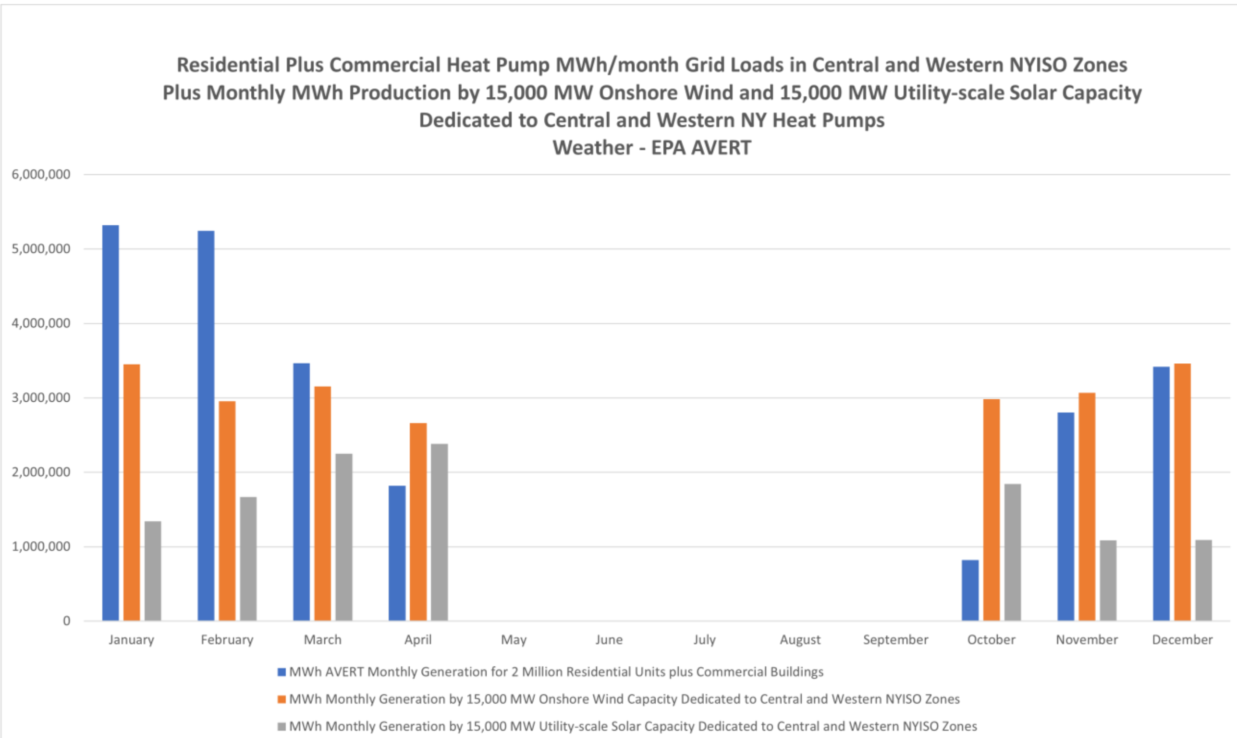


Figure 19. Monthly Grid Loads plus 15,000 MW Wind Capacity plus 15,000 Solar Capacity – Central and Western NYISO Zones

The graph above indicates that an installed nameplate capacity of 15,000 MW of onshore wind plus 15,000 MW of solar power will approximately meet the needs of residential and commercial heat pumps in central and western NYISO zones during the coldest months of the heating season, assuming the nearly unlimited availability of battery storage. If it were possible to install this 15,000 MW of onshore wind capacity at a cost of $5 million per MW, and the 15,000 MWh of solar capacity at a cost of $3 million per MW, the total capital expense would be approximately $120 billion, which translates to something over $60,000 per family. Such increase in cost per family, compared to downstate NYISO zones, results from higher heating loads and lower heat pump COP performance, both factors due to the colder climate.

For a central and western NY peak grid load of approximately 18,000 MW for heating, as indicated in Figure 17, the required worst-case, 48 storage capacity, to enable continued operation during extended cold temperature and low windspeed conditions, would be approximately 850,000 MWh.

If utility-scale battery storage were to cost $200,000 per MWh capacity, the capital expense for battery storage would be approximately $170 billion, or approximately $85,000 per family, to cover the 48 hour storage during a wind drought. As noted earlier, this figure may be subject to adjustment, however, based on battery material price increases or decreases which might occur as the wind and solar industries grow. Increased production volumes may contribute to economies of scale, which might provide downward pressure on costs. Increased volumes of mining and extraction of materials for batteries, on the other hand, could trigger higher prices due to supply shortages.

Recent capital cost analyses for residential heat pumps have centered on an approximate figure of $20,000 per onsite installation of residential or small commercial heat pumps. With the capital cost figures noted above for offshore wind capacity and battery storage, the total capital cost for full implementation of residential and commercial heat pumps in downstate New York could be about $165,000 per family.

SUPPLEMENTAL COMMENTS

USE PATTERNS AND FIELD PERFORMANCE OF COLD CLIMATE HEAT PUMPS SIGNIFICANTLY IMPACT EMISSIONS REDUCTION ASSESSMENTS

Studies of cold climate heat pump field performance, combined with electric use data, indicate that renewable liquid fuel use in heating applications is a more effective pathway to earlier, greater greenhouse gas emissions reductions. The transition to renewable liquid fuels can be achieved at a near zero cost to the customer, compared to cold-climate heat pump installations. Further, heating with biodiesel-fired heating systems has proven to be a reliable measure, compared to heat pumps, which broadly experience low utilization in winter weather due to reluctance to switch entirely to electric heating, as evidenced by consumer use patterns observed in multiple field studies.

Understanding real world electrical loads, cold-climate heat pump field performance and customer use patterns, using the most accurate science, allows the accurate assessment of a broader range of solutions to drive the maximum environmental benefits possible. Emissions factors rooted as much as possible in real-world measurements, rather than assumptions, are much less prone to error.

EVALUATION OF RESULTS FROM FIELD TESTING OF COLD-CLIMATE AIR-TO-AIR HEAT PUMPS

As noted earlier, the efficiency of cold-climate air-to-air heat pumps in the field has been documented as 20% to 30% below current manufacturer ratings. Based on the data included in the reports listed above, I have put together a series of graphs that illustrate heat pump performance and homeowner characteristics noted regarding utilization of their heat pumps.

The first graph below shows heat pump Coefficients of Performance (COPs) vs. outdoor temperature, as derived from the field testing studies. The graph includes average manufacturer ratings of heat pumps (red data curve) used in the various field studies listed above. The graph also shows actual field testing results published in the listed reports. The graph shows how heat pump COPs vary with outdoor temperature. It is also possible to see the trend of actual performance falling below manufacturer ratings for most studies.

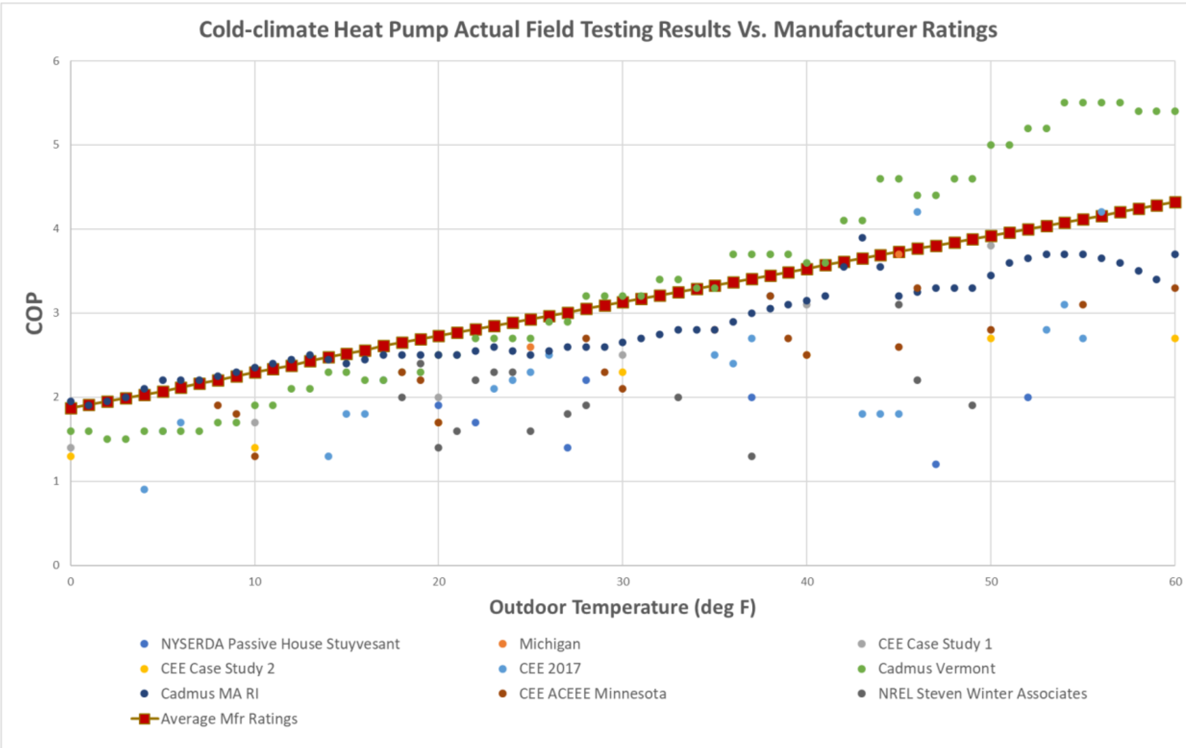


Figure 20. Cold-climate Heat Pump Actual Field Testing Results vs. Manufacturer Ratings

The next graph shows annual COPs measured by several of the field test studies. The graph shows manufacturer ratings for a representative sample of products used in the field testing studies (see gray bars). Actual cold-climate heat pump field testing results fall below manufacturer ratings. The green, yellow and red bars show measured COPs published in the reports, which noted that some results were skewed upward due to higher utilization during mild weather and lower utilization during cold weather. The two largest studies (Cadmus Vermont and Cadmus MA RI) noted particularly low utilization rates among the participating homeowners during the winter.

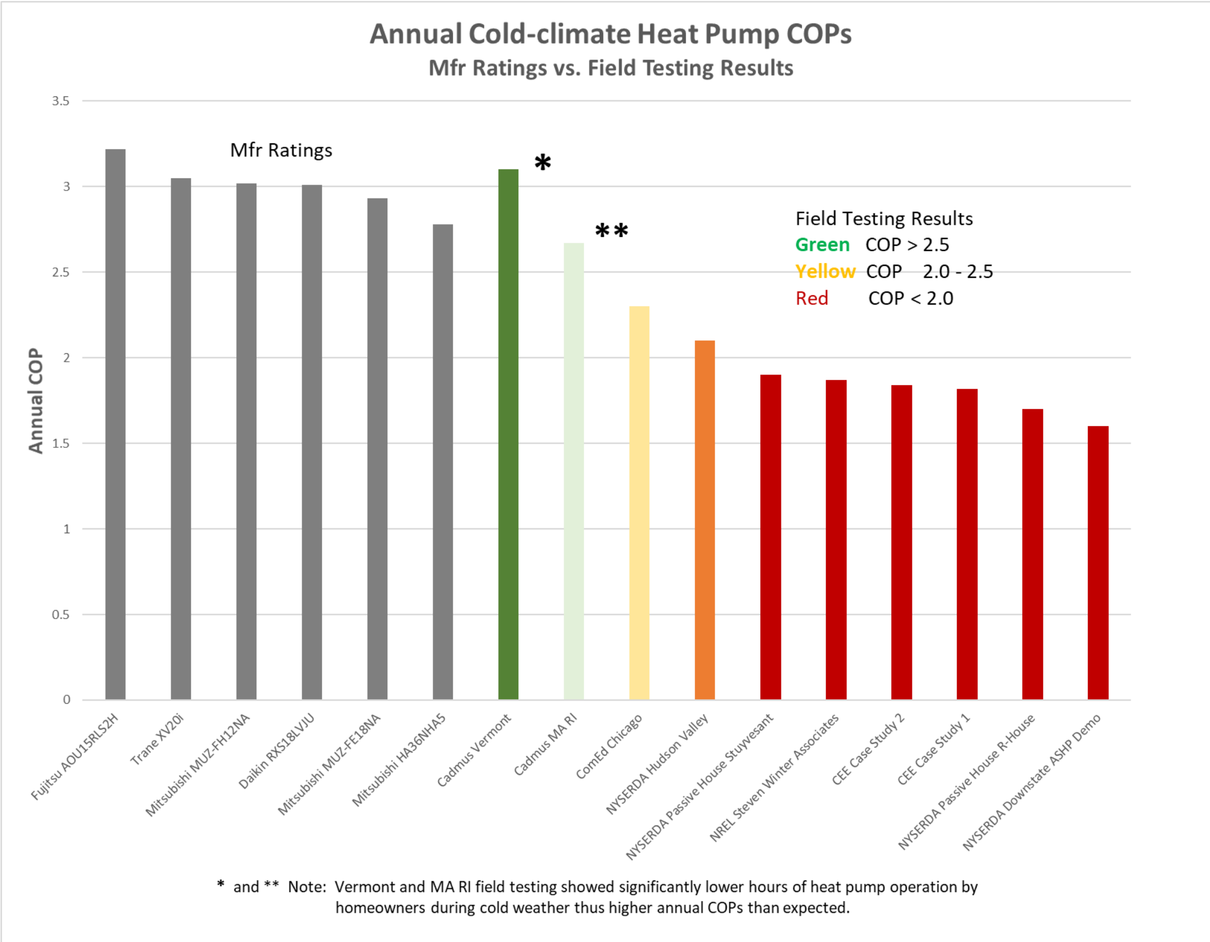


Figure 21. Annual Cold-climate Heat Pumps COPs

Annual cold-climate heat pump COPs indicate much lower field efficiency than manufacturer ratings. Higher reported field efficiency by VT and MA/RI field testing was due to low utilization in colder weather, not superior performance. Power demand graphs in the cited references indicate that the drop-out rate increased as the outdoor temperature went down. As noted again, such homeowner behavior resulted in artificially high measured, annual COP values since the performance data was skewed toward warmer temperatures. The remaining studies generally entailed, by design or mandate, a high utilization factor through the winter, but then lower COP values.

The manufacturer-rated seasonal COPs are generally around 3 or so, but the actual field testing results show values in the range of about 1.6 to 2.3 (see color coding of graph bars), which translates into a loss of about 20 to 30% from the manufacturer-rated values. The resulting conclusion is that, especially if the lower COP figures are combined with the use of marginal/non-baseload carbon intensity figures for power generation (instead of average grid mix figures), plus life-cycle analysis of natural gas used for power generation, the GHG savings of cold-climate heat pumps, compared to traditional oil-fired systems, are significantly diminished.

ELECTRICAL DEMAND OF HEAT PUMPS – REALITY vs. EXPECTATIONS

The graph below shows average electrical demand vs. outdoor temperature within the heat pump populations of the three largest field studies. The graph shows a representative electric demand for a full-sized heat pump with capacity of 40,000 Btu/hr at 0 deg F, also for a partial-sized heat pump with a capacity of 15,000 Btu/hr at 0 deg F. The data curves for the three field studies show that actual electricity consumption was only a small fraction of what would be expected with full heat pump utilization. Note that the actual electrical demand curves are relatively flat below 30 deg F. This indicates very low heat pump utilization below 30°F. Since heat pump power demand increases dramatically as the outdoor temperature drops further, due to increasing heat load plus decreasing heat pump COP, this means further that the homeowner percentage drop-out rate is increasing as the temperature drops.

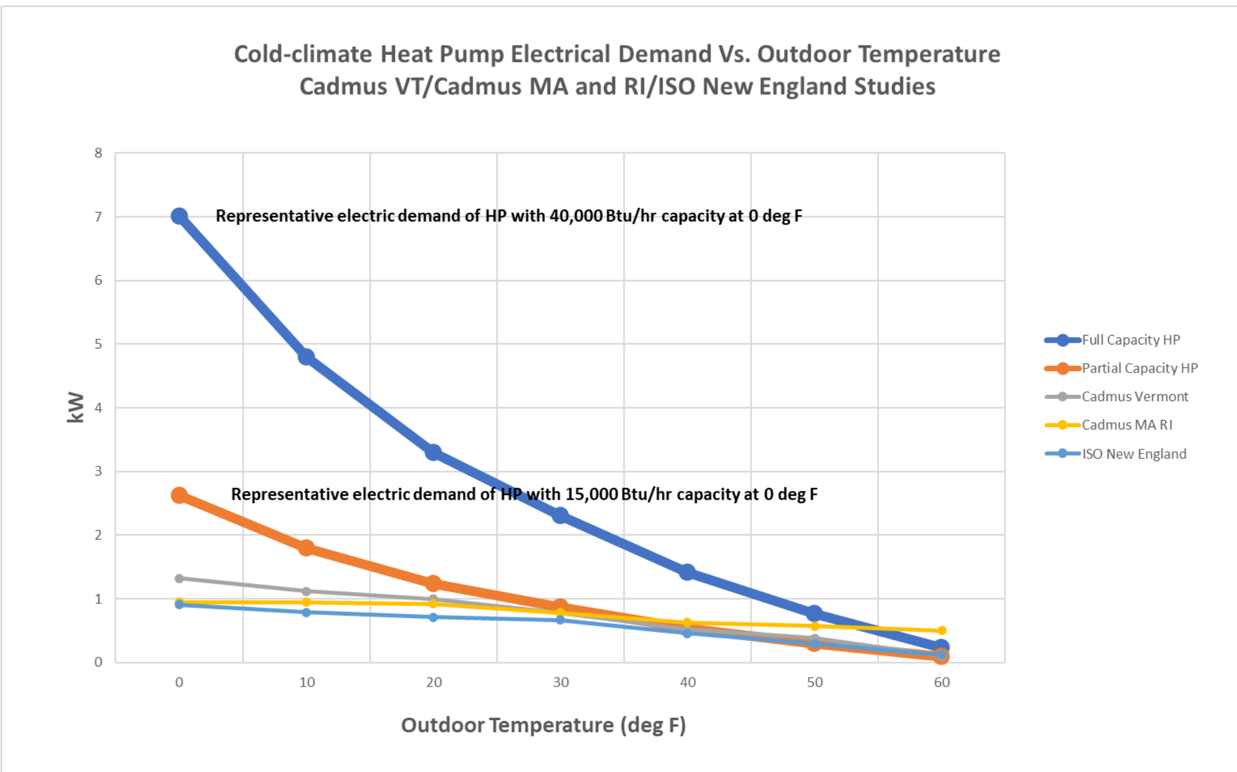


Figure 22. Cold-climate Heat Pump Electrical Demand vs. Outdoor Temperature

The bar graph below illustrates, in a different format, the same message re: low homeowner utilization of heat pumps during the winter. Homeowners have, on average, been using their heat pumps for less than half of the potential winter hours of operation. Some homeowners indeed used their heat pumps dutifully even during the coldest days of winter, but most dropped out at some point as the weather got colder, or never even turned on the systems at all for heating purposes.

This raises the thorny issue of homeowners taking advantage of heat pump incentive programs to purchase systems that are used substantially for cooling and only partially for heating, whether upfront incentives vs. pay-for-performance should be provided to homeowners, and whether ratepayer vs. utility shareholder funds should be used for heat pump incentive programs. There is direct relevance of the heat pump utilization question to policymaking for incentive programs in New York.

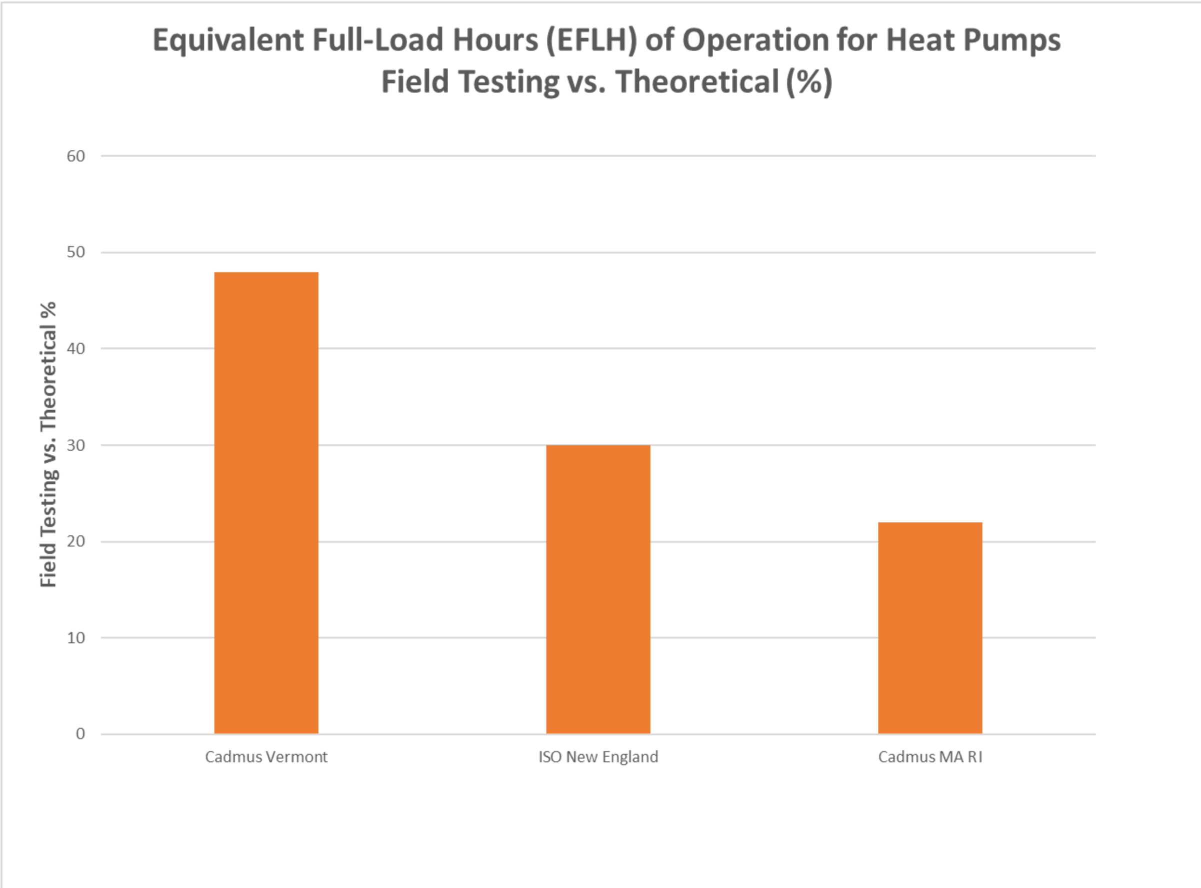


Figure 23. Equivalent Full-Load Hours of Operation for Heat Pumps

EXPANDING THE AVAILABILITY OF BIODIESEL GENERATES LONG-TERM CLIMATE BENEFITS

As stated in the stark UN IPCC 6th assessment released on August 12th, 2021, "It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred." Furthermore, the report states, "From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO2 emissions, reaching at least net zero CO2 emissions, along with strong reductions in other greenhouse gas emissions."

Simply put, reducing carbon emissions now, is more valuable than reducing the same amount of emissions later. This is because earlier reductions limit the long-term climate impact caused by the accumulation of greenhouse gases. This significant and often overlooked principle is frequently absent from policy discussions, which, for example treat a reduction of CO_2 in 2021 with the same weight as a reduction in 2050. This is simply not accurate and skews the market to seek low-readiness technology options which may not be deployed for years or decades, if ever at all.

Recently, The State University of New York (SUNY-ESF) published research to highlighting the value of early GHG reduction, limiting the cumulative heating impact of carbon emissions. This study compared the cumulative emissions reductions and associated societal value of using biodiesel today compared to waiting for a future, potentially lower carbon solution to be deployed later. These results demonstrated that when a technology with a low life-cycle GHG emission profile was deployed even five years later, it would generate less reduction in GHG emissions than a low life-cycle GHG technology deployed sooner. More simply, carbon reductions now are more important than carbon reductions later. The benefits accumulate, much like compound interest on a savings account.

While the current study was focused on transportation, it is likely to be expanded to cover home heating, including the use of biodiesel, electric heat pumps and natural gas. This work, which considered the timing of carbon reductions from a financial and economic standpoint has been echoed from a physical sciences standpoint in different journals by other researchers at UC Davis who have studied what they call, the 'Time Adjusted Warming Potential'.

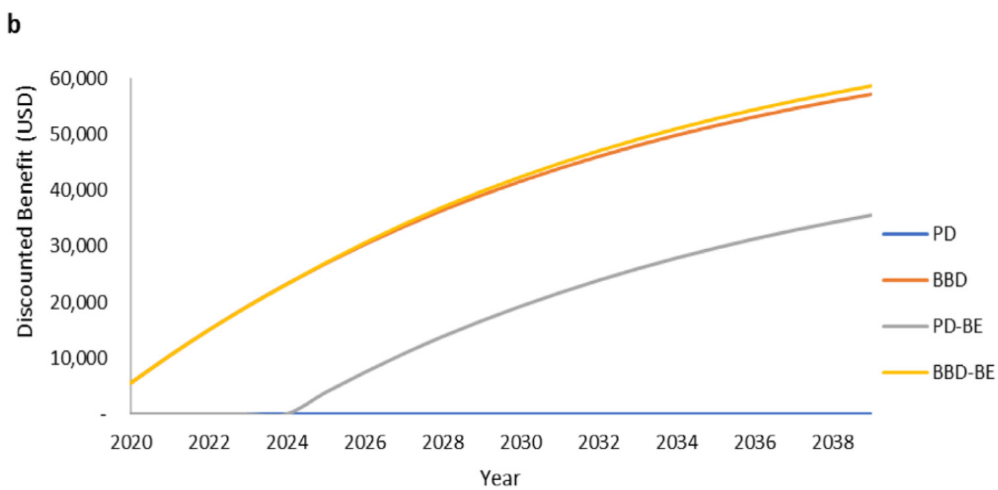


Figure 24. Time-based Sensitivity of Cumulative CO2 Savings for Biodiesel (orange) vs. Electrification Technologies (gray)

CO-BENEFITS OF BIODIESEL; BENEFITS BEYOND GREENHOUSE GAS REDUCTION

The increased use of biodiesel in home heating oil applications not only has significant GHG benefits as noted by researchers across the nation, but replacing diesel with biodiesel also results in a dramatic reduction in co-pollutants, sometimes called criteria pollution or tailpipe emissions. In particular, biodiesel can reduce diesel particulate matter emissions in home heating oil applications by 86%. These dramatic reductions can lead to significant health benefits in the form of reduce asthma attacks, avoided work loss days, and reduced cancer risk.

Often, the modeling framework to assess the health benefits from a reduction in criteria pollution employs a top-down method, estimating a reduction in specific criteria pollutant like PM, and assuming there is a normal distribution of these benefits among citizens. While this is appropriate to generally characterize the benefits of a policy designed to reduce these harmful emissions, it often fails to help decision makers and citizens truly understand how the reduction in these emissions will affect their local community and in what way.

To better characterize the health benefits biodiesel can generate in local communities who switch from diesel, NBB commissioned a study by Trinity Consultants, a globally renowned air quality modeling firm, who specializes in air dispersion modeling. Their work, which is published online, characterizes the benefits of these fuels much more granularly, allowing decision makers to understand where the benefits of reduced particulate matter, improved health outcomes, would occur and to whom. The results demonstrate that the use of B100 as a heating oil replacement reduces carcinogenic, diesel particulate matter emissions by 86%.

APPENDIX

NEED FOR USE OF MARGINAL EMISSIONS FACTORS FOR POWER GENERATION

On the Importance of Marginal Emissions Factors for Policy Analysis

Environmental nonprofits WattTime and Rocky Mountain Institute recommend marginal rather than average emissions factors be used for analysis of policies whose goal is to reduce carbon emissions. This primer explains why.

The purpose of average emissions factors is to apportion environmental responsibility.

A common technique in environmental analysis is to divide responsibility for cleaning up pollution equally between the different actors in a power grid on the basis of their relative power consumption. For example, if a given city consumes 5% of all the electricity produced in a given power grid, it is simple and intuitive to call it responsible for 5% of all the emissions in that grid.

The virtue of this technique is its simplicity. Each city or company on a power grid can simply calculate the average emissions per each kilowatt-hour on its local power grid; measure its own kilowatt-hours consumed; and multiply to determine its "share" of a given grid's pollution.[1]

Average emissions factors should *not* be used to measure environmental impact.

Historically, average emissions rates have been a convenient way to apportion "ownership" of different organizations' responsibility for emissions. Unfortunately, as momentum builds for institutions to more actively manage emissions, a worrisome trend is the growing number of organizations mis-applying average emissions factors to estimate the impact of environmental decisions. Yet this approach does not accurately measure environmental consequences. Returning to the previous example, it's entirely possible that the exact 5% of the grid's electricity that city is consuming comes predominantly from aging natural gas power plants, which would mean comparatively high emissions.

The correct way to measure environmental impact is using marginal emissions factors.

To protect against this mistake, the correct way to measure the impact of environmental decisions is to use *marginal* emissions factors.[2] Marginal emissions factors measure the actual environmental consequences of taking different potential actions on the power grid.

If the example city is evaluating an energy efficiency measure to conserve one megawatt-hour of electricity consumption, this program will reduce local emissions by reducing output at one or more power plants. But *which* power plants? Many sources of power, for example most solar panels, are designed to send all the energy they can to the power grid no matter the level of energy demand. Thus, they will be completely unaffected.

[1] See, e.g. the GHG Protocol Corporate Standard.

[2] See, e.g. the GHG Protocol for Grid-Connected Electricity Projects.

Conserving energy only affects some power plants: those which can scale up or down in response, known as the "marginal" power plants. Marginal emissions measure the emissions per kilowatt-hour only from these power plants, thus accurately measuring real-world results.

Why using average emissions can lead to incorrect policy conclusions.

When a power grid experiences a change in energy demand—for example, adding electric vehicles, or installing new clean power—that changes the emissions from local power plants. But some power plants are completely unaffected, for example, most solar panels and nuclear plants.

Using average emissions factors to measure the effect of environmental decisions implicitly assumes that energy policy-making affects all power plants equally. This overestimates the effects on these unaffected plants, and underestimates the effects on the marginal plants which actually do change in response to policy. If these plants have different emissions rates, this can lead to incorrect measurement of policies.

This is a growing problem because the more "always-on" clean energy a region installs, the more inaccurate any analyses using average emissions factors become. For example, on Friday May 3rd, 2019 at 1:30 PM, the CAISO website reported the following data regarding real-time energy supply and emissions. CAISO was delivering 23, 690 MW of power at an emissions rate of 3,042 $mTCO_2$/hour. Nearly 50% of the total supply (12,086 MW), was from renewable sources. Using an approach of average emissions, one would say that the current emissions rate was 283lbs CO_2/MWh.[3]

However, the marginal emissions rate for the same time was much higher, at 927 lbs CO_2/MWh. Despite the high penetration of midday solar, if 1 MWh of load was added to the grid at this time, the solar plants would likely not be the type of fuel responding to the increased load. It is more likely that an inefficient gas generator would ramp to meet the increased load, thus creating an emissions impact of 927 lbs of CO_2.[4]

As seen here, true emissions rates can be up to four times higher than average emissions-based estimates would imply, with major consequences for policy evaluation.

If policymakers were to only allow technologies that were below the average emissions levels, they might inadvertently allow existing, inefficient generators to operate more than they intend. The result would be restricting projects are that good for the environment, instead of encouraging them.

[3] California ISO real-time energy data.

[4] WattTime marginal emissions data.

Common situations in which marginal emissions is most important.

Marginal emission factors should nearly always be used in environmental impact analysis. Leading researchers apply them when measuring everything from renewable energy, to electric vehicles, to energy storage.[5] But they have particular importance for public policy whenever a policy measure is comparing different options, for example:

- *Comparing what times are best to use or store energy*. Marginal emissions should be used to select which times are cleanest, such as for energy storage.[6]
- *Comparing where is best to site a new energy asset*. Marginal emission rates should be used to measure the impact of new renewable energy, particularly in selecting locations.[7]
- *Evaluating electrification*. Marginal emissions rates should be used when evaluating the environmental impact of electrifying fossil fuel technologies such as vehicles, water heaters, and appliances. For example, in some coal-heavy regions, switching from a gasoline-powered car to an electric vehicle can actually increase, not decrease emissions.
- *Evaluating low-emissions energy sources*. Marginal emissions rates should be used to evaluate the environmental impact of low-pollution electricity generation technologies such as fuel cells and biomass. These technologies are sometimes mistakenly thought to increase emissions if they emit more than the local average emissions rate. But in reality they reduce emissions anywhere they less than the local marginal emissions rate.

For more information about average vs. marginal emissions, see this joint WattTime-RMI post.

How to properly design policy based on data-driven marginal emissions rates

Several large, influential public agencies (the CPUC), and private customers are committed to accurately reducing carbon emissions by using marginal emissions analysis. In December of 2018, the CPUC staff released a draft regulation directing the commission to require entities utilizing public incentives in the Self Generation Incentive Program (SGIP) to use marginal emissions rates to determine the net GHG impact of their project.[8]

Creating effective regulations and policy, as the CPUC has done, requires thorough data analysis and stakeholder engagement. As an independent, third-party non-profit, WattTime was founded to guide policy makers and regulators through this process to ensure that their efforts accurately reduce greenhouse gas emissions.

[5] See, e.g. Hittinger and Azevedo (2015), Callaway et al (2017) or Fares and Weber (2017).

[6] E.g. the California Public Utilities Commission's decision to use marginal emissions in real time for energy storage.

[7] See, e.g. Boston University's recent decision to buy renewable energy outside Boston using marginal emissions.